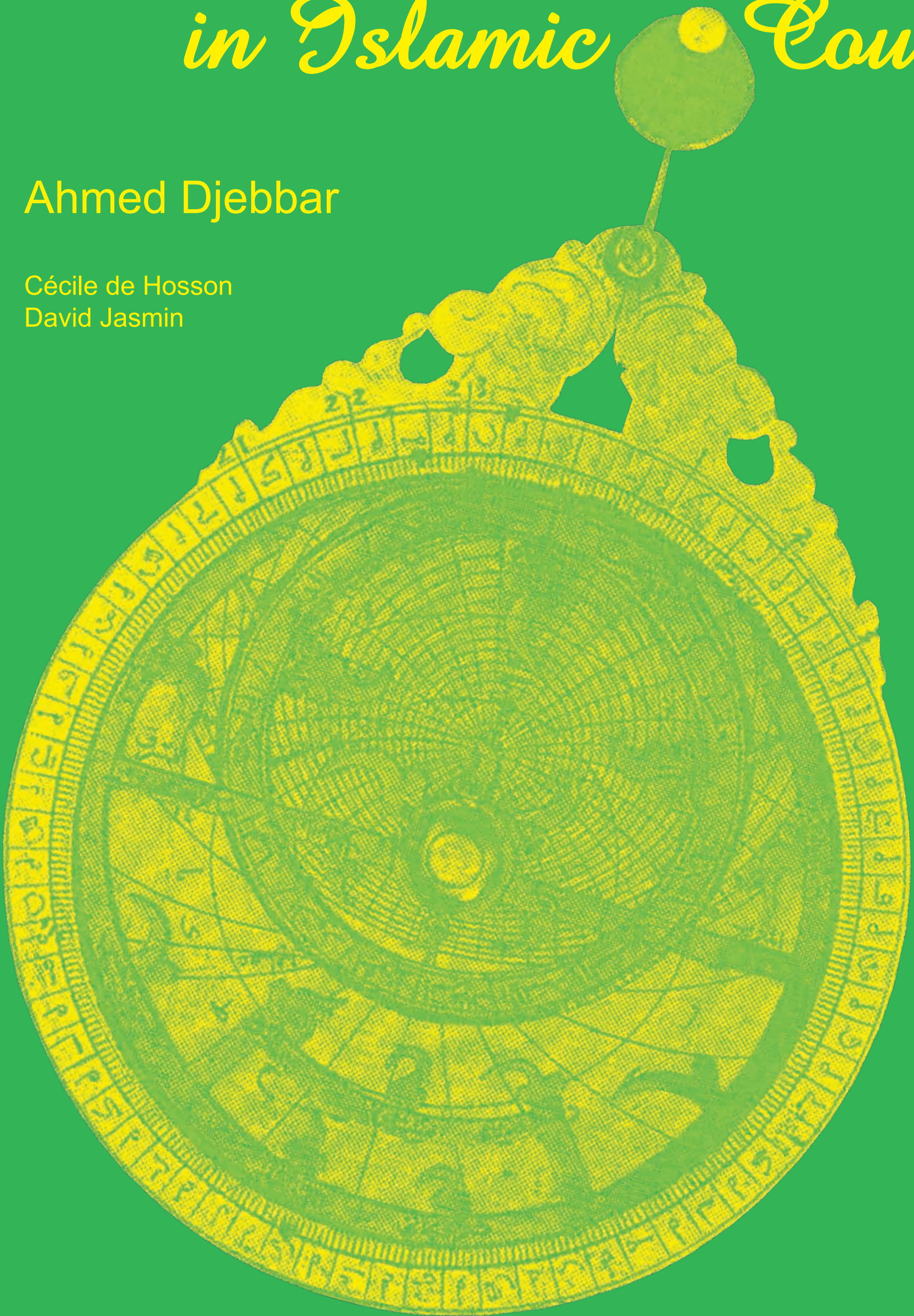
The Discoveries in Islamic Countries



Ahmed Djebbar

Cécile de Hosson
David Jasmin

la main à la pâte®

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ISTIC
INTERNATIONAL SCIENCE, TECHNOLOGY AND INNOVATION CENTRE FOR SOUTH-SOUTH COOPERATION UNDER THE AUSPICES OF UNESCO

The discoveries in Islamic countries

Produced by Ahmed Djebbar

Teaching coordination :
Cecile de Hosson and David Jasmin

This work proposes the means to set up the experimental activities from the history of science and technology. Its aim is to give scientific and technical knowledge to the pupils, from primary school, from historical stories, whilst also proposing the texts adapted for children and the documentation for the teachers. The originality of this work, whose teaching activities are designed for pupils finishing primary school and for college, is shown from the universal character of science, as in its inscription in different cultures. It shows the value of the scientific and technical discoveries in Islamic countries, by the savants, who have brought much to the whole of the scientific community and to humanity, in numerous domains.

In hoping that the teaching will be put into operation after having read this work, and that it contributes to give the pupils an image of science, more just, more personal, and more engaging.

Pierre Joliot
Member of the Academy of Sciences
President of the Committee of the trademark *La main à la pâte*

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Foreword

The book you will read is a concrete answer to all the queries which have been expressed at different levels by Professors teaching physical sciences. Those professors wish to impart certain notions to their students, as well as certain outcomes in Physics, Mathematics or Chemistry by introducing two new aspects.

The first new aspect falls within the pedagogical scope. The objective is to get those notions or outcomes to be discovered by the students themselves, by “putting one’s shoulder to the wheel” as it was said by Professor Charpark, meaning that students will have to undertake themselves the step-by-step approach which led to the discovery made by the researcher. In this mindset, this book allows students from the observation of a phenomenon, to ask questions, suggest various solutions for each one of them, test some of those solutions, before slowly discovering the path which leads to the right answer.

The second novelty is the cultural aspect. Before guiding the students in their research, the professor will share with them some information about the researcher who made the discovery, such as his vocational training, the society in which he has conducted his research, his working habits and, even at times, his mistakes while trying to solve problems.

Therefore, the book content allows all students to realize that the scientific field is within their reach through effort, curiosity and communication. The used examples demonstrate to them the evolution of science, without ever separating from it the human aspect, neither the environmental dimension, in which it is practiced. Similarly, they demonstrate the universal characteristic of science with the participation of all societies towards its progress and the use of borderless tools and methods.

As a result, this small book is recommended for all children in the world in order to make them love sciences, through a different approach, and to share with them some aspects of a great civilisation, the Islamic Civilisation, which has also contributed for centuries to greater knowledge.

I therefore wish to express my sincere congratulations for the publication in Kuala Lumpur of the English version of this book. I am confident that it will convince a great number of students, first in Malaysia, then in other countries, to keenly learn about science, with the hope that one day they will practice it with passion.

Ahmed DJEBBAR
Professor Emeritus
University of Sciences and Technology of Lille

Foreword

This publication of **“Les decouvertes en pays d’Islam”** in the English language is an exemplary effort by the International Science, Technology and Innovation Centre for South-South Cooperation under the Auspices of UNESCO (ISTIC) to disseminate knowledge on the scientific achievements of Islamic countries especially during the Golden Age of Islam. The Ministry of Science, Technology and Innovation Malaysia is indeed proud to be part of this noble effort and in lending funding support to this publication.

The achievements of Muslim scientists in the disciplines of astronomy, physics, biology, medicine, chemistry and mathematics are often poorly highlighted or forgotten. The publication of the translated version, ‘The Discoveries in Islamic Countries’, would make such information available to the English speaking public and especially to students. It would certainly serve as a source of inspiration as well as help to promote and enhance readers’ inborn curiosity and inquisitiveness as many of these intellectual discoveries have laid the foundations to modern science.

This publication is also testimony of Malaysia’s strong commitment towards attaining the objectives of Vision 1441 through science and technology for the socio-economic development of the Ummah.

Dato’ Madinah Binti Mohamad
Secretary General
Ministry of Science, Technology and Innovation
Malaysia

Foreword

In recent decades, there has been increasing concern throughout the world that the enrolment of science, engineering and technological (S.E.T) courses in universities continues to decline. This is having serious adverse consequences in confronting the challenges of global poverty and climate change.

Many national S.E.T organisations, especially national academies of sciences have been resolved to do whatever they can to help national governments to arrest and if possible, reverse the alarming decline. They realise that part of the solution must lie in arousing the interest in S.E.T in the young so that they will pursue S.E.T courses in universities and eventually join the S.E.T communities in combating the challenges confronting humankind.

One of the outstanding successes has been the “La Main a la pate” (LAMAP) programme of the French Academy of Sciences. This primary-school inquiry based science education (IBSE) programme has galvanised primary school science teachers and students towards S.E.T. In France, LAMAP has now become a national IBSE programme and has spread downwards to kindergarten and upwards to secondary school level. Through international cooperation initiatives of the French Academy of Sciences, LAMAP has also spread to many parts of the world. In our region, the most successful are the “Handsbrain” programme of China and the IBSE programme of the Regional Education Centre for Science and Mathematics (RECSAM) Penang Malaysia.

One of the most commendable initiatives of LAMAP is the incorporation of scientific experiments from the Golden Age of Islam through the publication of the book “Les decouvertes en pays d’Islam”. These experiments by Islamic pioneers in S.E.T predate similar European experiments by several centuries. Yet only the latter European inventors are universally recognised. This promotion by LAMAP of the universality and continuum of S.E.T is most important when the global village is shrinking through the fruits of S.E.T whilst the gap of trust and understanding has not narrowed.

ISTIC fully describe to the above philosophy and is pleased to translate the French book into English so that it can contribute to IBSEs to more parts of the world.

ISTIC hope that this will spur developing countries to incorporate their indigenous historical S.E.T discoveries in their IBSE programmes. This measure will no doubt enhance national confidence and pride in the young. National pride and self confidence are essential ingredients in social and economic development.

On behalf of ISTIC, I would like to thank my good friends, Professor Ahmed Djebbar, the book's author, and Professor Yves Quere of the French Academy of Sciences and of LAMAP for their kind permission to allow the publication of this English translation of the book. Similar appreciation goes to the publisher, Le Pommier.

Finally, our deepest gratitude is extended to the Malaysian Ministry of Science, Technology and Innovation that provide the crucial funding support in its capacity as the Secretariat of OIC Vision 1441.

Academician Dato' Ir. Lee Yee Cheong
Chairman, ISTIC Governing Board

Foreword

The idea for this book has a very precise origin.

April 2005. We were meeting in Islamabad, under the aegis of the Pakistan Academy of Sciences, for a symposium on the development of the sciences in Islamic countries, which development many of the participants, from those countries, deemed to be insufficient. They said that science is not held in its proper place by the public. In particular, they added that schools do not give a sufficient status to it, or that it is often taught there in a bookish and boring way. In both cases, children do not develop an attachment to it. This lack of interest is added to by the impression that this is a subject that belongs to a world which is not their own, like a train which one watches go by, but in which one has not taken one's seat.

Being at that time Co-Chair of the *InterAcademy Panel* (IAP), the Assembly of all the Academies of Sciences throughout the World, and taking into account that the IAP had made the teaching of science in primary schools its main flagship, I found this apparent failure distressing. Since we had also encountered this problem in Europe and in particular the discouragement of teachers in the face of a science which was felt to be too difficult, we had published a book entitled *L'Europe des découvertes* (Europe of Discoveries)1 in France, 2003. In it, we gave a simple description, with an historical linkage, of a number of discoveries made in various European countries, which could be reproduced in schools by children: Portugal's new shape of a veil for ships (14th century), France's first hot air balloon (the *Montgolfière,* 1783), Germany's chemistry of food by Liebig (19th century), etc.

Transposing this idea to the scientific discoveries of Islamic countries, I suggested that a book of this kind should be written specifically for children of those countries. Just as in the case of Europe, it was never in my mind in this case, to stimulate even the slightest chauvinism in these children, which would run counter to the scientific spirit. The idea was simply to remind them of the richness of their past in the field of science and how they might draw inspiration from it for their own intellectual education, the knowledge of their history and, possibly, the choice of a subsequent career in scientific research.

The idea was received very favourably, and soon a group set to work under the supervision of the mathematician Ahmed Djebbar, a leading specialist in the history of Arabic sciences2. And so it was that, under the pen of Cécile de Hosson and David Jasmin, two tireless propagandists for *La main à la pâte*, a number of discoveries due to al Haytham, to al-Zarqâli…, were made available to children3. Not only are they able to read about these discoveries, but above all they can reproduce the corresponding experiments at school or with their family, and take inspiration from these great examples. Thus, science can appear to them, in its universality, like a magnificent school of thought, a great lesson in tolerance, liberty and democracy, and a vital force for economic development4.

I am very grateful to ISTIC, and in particular to Professors Dato Lee Yee Cheong and Dato Samsudin Tugiman for their decisive role in the translation and the publication of this book in English, and also to the publisher *Le Pommier* for looking favourably on the idea. May this book stimulate the expansion, in Islamic countries, of a teaching of science which takes the form of *Inquiry Based Science Education* (IBSE), as Georges Charpak, Nobel Laureate for physics, had been wishing5, a form which is presently spreading throughout the World!

Yves Quéré
Former IAP Co-Chair,
Académie des Sciences, Paris

Preface

From the middle of the VIII century to the end of the XVI, a new scientific tradition emerged then it was developed in numerous towns and the immense territory conquered in the name of Islam between 632 and 751. It was from this double heritage, as shown in the sphere of past civilisations, that the new learned persons began to form themselves.

The first heritage regrouped the savoir-faire, often ingenious, that were practised and transmitted, orally and on initiation in the world of corporations, particular professions or activities. This was the case of the knowledgeable who dealt with generally, by commodity, to be classed in the following groups: military or civil technology (water based systems, automations), chemistry (treatment of glass and colours, cosmetics, metal works), administration and calculations for transactions, geometry, land surveying and decoration etc. The comparative study of these methods and techniques reveals the diversity of their origins and their links with different cultures in which they occurred.

The second heritage comprises of the theories or applications of knowledge which have been preserved and circulated in writings. They were produced generally in Greece, India, Persia, Mesopotamia and to a lesser extent the Iberian peninsula. The results of their enquiries have not been the same all over: a great part of Greek sciences were hypothetically deduced, those of India, Persia and Mesopotamia were due to algorithmic and experimental methods.

This diversity had the same goal, that of establishing the results and making tools, characteristic of the first scientific footsteps in Islamic countries were disparate elements of knowledge coming from diverse cultural horizons, having firstly been juxtaposed before making the object arising from a prolific amount of suggestions and giving a unified expression across the Arab world. It is also from the IX century, that a network of scientific establishments were set up, in towns such as Baghdad and Damascus at the centre of the Empire, Samark and in central Asia, Kairouan au Maghreb abd Cordoba in the Iberian peninsular. From the end of the X century, its centres would come together with others, all just as dynamic, such as Rayy in Iran, Cairo in Egypt and, a little later, Toledo, Saragossa and Marrakech in the Muslim East. It is important to remember that, in all these centres, science was practised in the same fashion, according to a norm that you could describe as "universal", that is to say did not depend on any specific denomination, ethnic or cultural identity, apart from the unity of the language of expression, that we have already evoked, and that is the only justification for the mode of expression of "Arabic science" to design this together in practice.

After a period of more than a century where this was known, from the first heritage, which was to work in different sectors of activity in the Islamic city, the need to access the contents of the second heritage, starting by formulating and improving some of the first translations, which were financed by the caliphs and other high persons of the State. But, from the end of the IX century, these initiatives experienced a great amplification –right through to the middle of the X century- carried by civil members of the society not necessarily belonging to the courts of caliphs and princes. As this society was cosmopolitan, multi-denominational and multi-cultural, it is not surprising that this long-time activity of translation reflecting its diversity (even if the Arabic libraries note the strong participation of the Christian communities increasingly in the activity of translation). It must, finally, be added, about this phenomenon, that its duration is explained by the development, in certain groups of society, of a real demand. The member of these groups were generally less well off than the patron caliphs but relatively more numerous. Amongst them, it is interesting to note the presence of eminent scientists such as al-Kindi (died circa 873) and the brothers Banû Mûsâ (IX century).

These translations concern all the scientific and technical domains as were practised in the previous civilisations: astronomy and Indian medicine written in Sanskrit or Persian writings in pehlevi, texts in Latin dealing with astrology and medicine, treatises of nabatéen agriculture. . . To this modest amount, you must add, much more importantly, produced within the framework of Greek scientific and philosophical tradition since the V century B.C. It is this material, which after translation, has added to or impregnated all the disciplines practised in Islamic countries, even those who have originated contributions to the new civilisation. There was, in the first place, mathematicians, with their different orientations, which were designed from the end of the III century: numerical theories with Pythagoras and Nikomacheia, plane and cubic geometry of Euclid, conic geometry with Apollonius, and geometry of measurement with Archimedes. In close relation with his disciples, he also studied astronomy, (models of planets, astronomical tables, instruments for measuring) and physics (statics, hydrodynamics, optics). At the time there was all the sciences as one considered them as not Arts; Greek heritage: medicine (physiology, anatomy, pharmacopaeia), mechanics (ludic or utilitory) chemistry (experimental or esoteric), botany, zoology, agriculture, etc.

As the discoveries and innovations in this book unfold themselves, they are divided into six categories, it seems practical to describe them, briefly, the development of each one is placed in order to show its original contribution which is the object of this book to show the general development of the science to which they refer.

Mathematics started off in Islamic countries, from its practical aspects, which refer to the different economic needs (accounting, commercial transactions), justice (division of inheritances) and arts (architecture, decorations). Some ancient chapters have been reactivated, such as the procedures for mental calculation, the Indian arithmetical procedure based on the system of positional numbers (with the zero), geometry tools to make the architectural shapes and to copy the figures in two dimensional decorations. It is within this frame-work that they have valued and perfected the geometric steps and techniques (symmetry, rotations, calligraphy, and that of the mosaic).

The second great orientation of mathematics is purely theoretic in the sense where the researchers wanted to solve problems that their Greek predecessors had stumbled on or new problems that they had been set, or other sciences had asked them to solve. Sharing the results and the steps that were inherited from the Ancients, they started off by commenting on them, sometimes criticising them, then reflecting on the foundations of their discipline, to elaborate on the thesis, before developing them in new ways. Certain ones, as algebra and trigonometry, were extensions and enrichments of old practices. Others, as combination analysis and magic squares were suggested then favoured by a cultural context.

From the start, astronomy had the attention of the State. Certain caliphs not only financed the translations but also made certain orders to the leading astronomers: the compiling of calendars and geographical maps, the determination of the direction of Mecca, calculation of the times for everyday prayers. Always in response to the needs, this time in response to particular people (merchants, pilgrims, men of science), interest in ancient instruments (planispheric astrolabes, solar bodies) which were redressed and perfected, such as was described in the chapter " from al-Khwârizmî to al-Zarqâlî, the astrolabe became the king of instruments". Later, and in the scope of optimisation (lightening instruments) new instruments were invented (the universal astrolabe, sines).

But astronomy had had an important theoretical wing that one knew less and had perhaps constituted a decisive stage in the development of this discipline, even across some of its checks. In this domain, the work concerned the realisation of numerous astrological tables for all uses, the conception of models of new planets to replace those of Ptolemy which, which having reigned for centuries in astronomy were no longer considered as satisfactory. They even had, at the beginning of the XI century, in central Asia, discussions on the theory of the Earth's rotation on its axis and that of its rotation around the sun. These hypothesises were finally abandoned, not for theological or philosophical reasons, but for reasons judged as scientific in their time.

In physics, and in an extension of Greek traditions, four disciplines were particularly developed: statics, dynamics, hydro-dynamics and optical. Three of the contributions as presented in this book illustrate the vitality of these domains: the scales of wisdom of al-Khâzinî (XII century), the theory of light of Ibn al-Haytham (died 1041) and the rainbow theory of al-Fârisî (died 1319). It is important to state that the contributions were not the end of the investigations that had started, for certain among them, at the start of the IX century. To take for example optics, the sources we learn first researched concerned mirrors, which interested first of all the military, because they could be used to start fires and so burn the fleets and fortresses of the enemy. Then there were the theoretical preoccupations on the technical aspects. Led by al-Kindî, Ibn Sahl (X century) and their two successors; these studies concerned the physiology of optics, the laws of reflection and refraction and certain light phenomena that can be seen in the sky.

Arab medicine, solidly anchored in the galénic medical tradition, seems to have had trouble to free itself from its ancient conceptions and convictions. But this did not impede the innovation in certain other domains. Its most significant contribution, by amplitude and duration, has been the setting up of a medical hospital, financed firstly by State representatives then by members of the society with the help of waqf (Assets belonging to the state that can't be sold). Certain of these hospitals even had sections for the mentally ill. They also had advances in anatomy (knowledge of certain bones in the human body), in the diagnosis of certain illnesses, in the practice of surgical instrumentalisation, in particular with the contribution of Andalusian az-Zahrâwî (XI century), and in the elaboration of great medical synthesis, such as those of Ibn Sîna (Avicenne, died 1037) and of ar-Râzî (Rhazes, died 935), who directed medical teaching in Europe until XVIIth century. But it was in physiology, with the discovery of the small circulation of blood, which is described in the chapter "the discovery of pulmonary circulation by Ibn al-Nafîs", that a new road was followed. Unfortunately, this was abandoned by the medical community of the era (XIII century) which stayed faithful to the Galien theory, confirmed by Avicenne.

In mechanics, it was in response to civil and military needs that the works of Héron of Alexandria, Archimedes, and Philon de Byzance were translated into Arabic. After having adapted and perhaps bettered their contents the Islamic countries' mechanics set out to innovate, in particular automations and hydraulic systems. It is in this last domain that they updated and applied the conical valve, the camshaft, the piston and the crankshaft. Certain original ideas were already thought up in the book of the brothers Banû Mûsâ. But it was with al-Jazarî (died in 1206) that you hear the most numerous and significant innovations, as those that we presented here, in the chapter "the al-Jazari (hydraulic) water pump".

Chemistry with medicine is the discipline, which, it appears, the best to survive the decline of the ancient civilisations of the eastern Mediterranean. This explains its precocious reactivation in the sphere of the new civilisation. in effect, from the start of the VIII century, it has assisted with the constitution of a solid tradition in this domain with, as the undisputable animator, the famous Jâbir Ibn Hayyân (Geber), whose works together with those of his disciples, abound in original results. after them, different chemical practices were developed, such as calcination, sublimation, purification, and above all distillation, which had substantial progress, as is shown in the chapter "Introduction to Arab alchemy". Always in the framework of the theory of the four elements inherited from the Greeks and refined by Jâbir, these works added to the description of substances not previously known about, the setting up of mineral acids and the elaboration of new classifications of analysed products. Among the scientists who have taken part in these advances are al-Kindî and Abû Bakr ar-Râzî.

One part of the contributions that we are going to present briefly has started to circulate, relatively quickly, outside the borders of Islamic countries, in particular towards Europe. The figures called "Arabic" and the astrolabe arrived in the south of Europe at the end of the X century. Some works of medicine published in Baghdad and at Kairouan have been transcribed in Latin by Constantine the African in the second half of the XI century. But you have to wait until the start of the XII century for this activity of translation (from Arabic to Latin and Hebrew) to grow. At Toledo and Palermo, where this phenomenon had its seat, dozens of young Europeans freshly 'arabised' were engaged in this with a passion, supported and financed by enlightened men of the church and, later, by the Castilian king Alphonse X the wise. Their work allowed access for men of science and practitioners to the rich inheritance in origin Greek, Indian and Arab cultivated and elaborated on in the Muslim world since the IX century. The assimilation of these rich contents opened the way to new investigations which were, in their turn, contributions to modern day science.

In conclusion, it remains for us to make a few remarks on the nature of the scientific activities of Islamic countries, in the sphere of which the discoveries presented here have been realised, and on the actual gateway of these discoveries.

It should be first of all stated that as the scientific practices which are going to be briefly described here, during each of their phases, in a context of intercultural exchanges, which are never contradicted. The scientific historians have even observed the totally non religious character of these practices, which may be at the level of their contents, of their formation, of their approach, or discussion which has been produced on the scientific production itself. This aspect only serves to reinforce the universality of the science produced in Islamic countries, favouring, just the same, their circulation in Muslim cultures and in Christian cultures of medieval Europe, and this in spite of the religious antagonisms that are sometimes expressed from the advent of Islam and which are deepened from time to time, particularly, at the time of the crusades (end XI – end XII centuries).

As to the discoveries presented here, they are certainly constituted on a time, largely well passed, in the elaboration of science. But they are more than that. In effect, by the motivations which have animated their authors, by their approaches and their goals that they have met, they witness, further than the specificity of each of them, from what appears to men of science from different eras and cultures: an instant curiosity, patient observation of studied phenomenon, taking things into account, with a critical attitude, in relation to your predecessors, obstinate research of the truth, comforted by the unbreakable faith in the capacities of science to surpass all obstacles. It is this lesson, finally very modern and universal, that the authors of this book have read in the contributions of some of these Islamic savants, and that they want to render it accessible to the teachers and their pupils.

Ahmed Djebbar

Science in operation, a living history

Archimedes and his bathtub, Newton and the apple, Pasteur and the child saved from rabies. . . The majority of us remember the anecdotes that have occurred in the course of science. When the history of science is invited into the classroom, it is often in a reduced format, relayed by the biographies of illustrious savants taken from numerous scholarly manuals. Otherwise, the school leaves little space for the subject of the history of science: the discoveries and the laws which describe the world are generally presented as completed works autonomous and almost eternal, but the roads that led to this achievement are too often neglected. However, science and its techniques as it is taught is the result of a long history, dotted with genial institutions, stuttering and starting, debates, controversies. . . a history of men and women who do not ignore any geographical territory or culture. We have attempted to elaborate here a work whose main aim is to surpass the common places of the history of science and its techniques to plunge the master and the pupils live and breathe the living science.

Presentation of the book

Discoveries in the Land of Islam is aimed at year 3 and the first years at college. The work suggests that they study and reproduce, from simple materials, a major discovery or an exceptional technical invention that has come to be called “the golden age of Arabic science” (from the VIII to the XVI century).

The structure and the contents of the Discoveries in Islamic countries rest on two essential ideas. The first is that the historic perspective allows us to take the measure of the efforts and controversies associated with the elaboration of a law, of a concept or the resolution of a technical problem. . .The second is the transposition, in class, of this historic road, of its queries and stakes, and allows us to approach that science and to show how the questioning and formulating of the hypothesises make up the fundamental basis of a scientific approach in reality. More than the chronicling of a simple discovery, it forms the anchor for the experimental activities at the heart of the scientific base, to familiarize the pupils with the dynamics of the time and to react the activities of the researcher as he would have done when making the discovery. This done, despite the vast distance that separates a savant of the X century from a French primary school pupil, it is finally a scientific question of the same experience, of its stutterings and controversies, which can be brought to life. Suggesting an apprenticeship for applying certain fruitful historic ideas can be as rich an assignment for the pupil. . .as for the teacher.

This work presents eight accessible discoveries for pupils from ten to thirteen years: the theory of sight, the water pump, the still or alembic, the theory of the rainbow, five tray (receptacle) scales, the discovery of pulmonary blood circulation, symmetry in ornamental Muslim art and the astrolabe. Each of these discoveries, is set in its historical context, witnesses the diversity of the Arabic sciences but also the start of the experimental system in the savants' works of their era. Each one allows us to take part in activities to investigate them in class and to conclude with them, according to the capabilities of the pupils, of the numerous points in the scholarly program. To aid the teacher to set up these activities in class, each one, is accompanied by three complimentary texts.

The historical texts allow us to reconstitute the scientific basis of the discovery within its scientific, technological and social contexts. They witness the obstacles, the leanings, but also the fundamental ideas or the great intuition founding the scientific discoveries and its techniques that we have retained. Directed by the specialist historians of the treated subjects, these texts will complete (or reactivate) the scientific culture of the teacher in order to help to satisfy the curiosity of the children and to have the confidence to set up the activity in class.

It also gives, at the same time, a detailed support for certain of the difficulties that the pupils will come across in the course of their learning curve. This could be, for one thing, to guide his teaching manner where it is not covered, and another, to lead in a manner to best appreciate the errors and hesitations in the pupils' investigations: the historic stutterings also explain these –probabilities- of the class, advising on the errors committed and on the time allocated to the elaboration of certain knowledge.

The teaching texts present the activities to be carried out in class have been precisely thought out to place the pupils on the same historic road in the spirit of invention and discovery. Having been tested in scores of classes for two scholarly years, these activities show the set up of the investigation and the history of science by several approaches: the reproduction of a historical experiment, documentary research (textbook reference work), reading of fictional texts, watching a multimedia animation. . . The proposed sequence here, does not necessarily follow a chronological order of the historic events so that the teaching can be held as the main criterion, with the age of the pupils and within the constraints of the experiment in the classroom, whilst leaving an active part for the pupils to progress in the acquisition of contextual knowledge.

To offer a large choice of activities for the teachers, we have ranked the diversity of the treated subjects while leaving the possibility, for each subject, to be adapted and enriched during the teaching in class. You therefore do not find here, a
key guide but the sequences of the illustrated activities of numerous works in class and preceded by a list of the necessary equipment as well as the notions of the program which can be shortened or lengthened.

The children's texts are about a discovery from a fictional angle. Inspired by eastern accounts, they introduce Nabil and Fadila, two curious children, whose adventures and questions serve to give us a starting point for the class: you can use them as a stimulant for the imagination, giving rise to investigations and discussions.

The historical approach and set up of the investigation

The privileged historical perspective in the class's activities does not modify the set up of the investigation of la main a la pâte, but should encourage the pupil to question, observe, formulate hypothesis, experiment, argue. . .

It is no longer used to agree in an anecdotal manner but offers the possibility to the pupils to gain a historic contextual knowledge and to take little by little a realisation of the complex relation between the universality of knowledge and its cultural and historical construction.

This work evokes the history of Arabic sciences, a misunderstood history and still too little studied in primary and secondary education. In proposing the richness of its scientific and technique discoveries carried out between the VII and XIV century in Islamic countries, we echo the cultural diversity which characterise the French classes of today and want to show the pupils and their teachers that the history of eastern sciences and techniques owes much to dialogue and exchanges with other civilisations, of other cultures and geographies. In introducing to the school this historical period of science, we want to salute and learn about the extraordinary science and technique production of the arab-muslim culture but also to distinguish the relation of today's cultures in France associated with the most recent immigrations to the making of a universal shared knowledge.

The multimedia tool

To complement this work, La main à la pâte have created an Internet website dedicated to a collaborative project (www.lamap.fr/découvertes). Each discovery is explained there by an animation designed for children which serves as taking the teachers lead for directing the activities in class. The teaching texts suggest how to use these tools in the proposed progressions. The teacher will even find on this site extra written work and some of the book's illustrations in high definition. This site also allows the classes to intermingle and exchange their work and to make reference to the Discovery Encyclopaedia redirected for their needs. The pupils can also, from their illustrious predecessors, leave some of their researches online and consult with those already uploaded, by other classes inscribed to the project.

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Ibn al-Haytham,
light and vision

How do we see the things that are around us? What physical phenomenon explains that this book that you have in front of your eyes is . . . visible? Today, such questions make you smile, and, no doubt, you would have no problem in answering it: if things are visible, it's because they have sent some light that our eyes have received. Behind the apparent simplicity of this answer there have been many quarrels over the centuries. And we must go to the beginning of the XVII century when the physician Johannes Kepler put forward a term in proposing a geometric theory about vision: that of the retinal image. This theory would never have seen the light of day, had it not been for an Arab savant by the name of Ibn al-Haytham who, in the XI century, became involved in the mechanics of vision in an altogether original manner: for Ibn al-Haytham "light" became an entirely physical concept, and for the first time, the experimental method appeared as a framework as to how to determine scientific discoveries

Before Ibn al-Haytham: the Greeks

From the V century B.C., numerous savants tried to explain the phenomenon of sight, without arriving at a conclusion. Certainly, sight produces a "fire of sight", sent by the eye, to meet the surface of an object to be seen. This theory is followed not only by such savants such as Euclid and Ptolemy, but also by the stoics[1]. Also, in the II century B.C. the great doctor Galien supported the idea that the eye sent an invisible substance to the objects to be seen, the “pneuma”, a sort of tenable excrescence with the properties of a stick. In opposition, the atomists, amongst whom Democrates, Leucippus, and much later on, the poet Lucrece, explained sight in a different way: objects are continually sending replicas of themselves, *discharges, imitations, or eidola* in Greek, which flutter about in every sense and rest on the air, which, itself, rests on the liquid of the eye, a bit like making a pad out of wax. As for the light itself, its own nature is not investigated.

Further to this there are other theories, which we will deal with later, the idea that an intermediary agent emerges from the IV century B.C., by Aristotle. He said that sight is, as the other senses, a process which occurs when a sensory organ (nose, mouth, eye etc) detects “movement” by a specific impression coming from the objects, “the correct sense”. And for Aristotle, the “correct sense” of sight is the colour: “The sensation consists of movement and detection (. . .). I call correct sense that which cannot be perceived by another sense and that which leaves no possibility for error: such as for the view of colour, to hear a sound, for taste - savouring[2].”

The savants of medieval and pre-classic western science will inherit the controversy about the “sense” of the view and will review their understanding of the theories of “visual fire” and “imitations”. In spite of the marked contributions from the English thinkers of the XIII century, such as, Robert Grosseteste, Roger Bacon and John Pecham[3], the arguments were lost in Europe until the beginning of the XVII century, as it was already in force in XI century Egypt, Ibn al-Haytham argued the first principle of the physical concept of “light”, which was going to make a decisive advance in the history of vision’s optical mechanics.

Ibn al-Haytham and the theories of vision

Abu Ali al-Hasan ibn al-Haytham (Ibn al-Haytham) was born in Basra, Iraq, around 965 A.D. Attracted to the effervescence of intellectualism that was reigning in Egypt, went to Cairo in the reign of Caliph Fatimide al-Hakim. He undertook the writing of *the Book of Optics, the Kitah al manazir,* in which he described in minute detail all the stages of the explanation of his new model of sight. This explanation is linked to an approach where experimentation plays a key role: each theoretical advance is presented as coming from observations made in the course of wisely thought out experiments. Throughout this book, ibn al-Haytham became without doubt the first person to carry out experimentation.

In the first lines of the *Kitab al-manazir,* Ibn al-Haytham took part in the debates about the holders of the “visual fire” and those for the “imitation”, rejecting in a radical fashion the theories of the former[4]. For this, he took recourse to two phenomenon easily observed: the dilation of the pupils of the eye and bedazzlement. Let’s start with bedazzlement. If a person is bothered when he looks at the sun, it is because the eye is not active in the vision process and that he is not sending any “visual flow”. If this is the case, the observer should be capable of controlling the sent flow, and should have no reason to suffer when looking at one object rather than another. The eye is therefore passive and sensitive to an outside agent, which he, to a certain degree, can control. Certain of this, Ibn al-Haytham, held the anatomical descriptions of the eye to which he dedicated a full chapter in his optical treatise.

The role off each part of the eye was explained and the pupil was described as a small opening susceptible to grow or to retract its size under various exterior effects. Otherwise, Ibn al-Haytham, did not subscribe to any of the theories of the atomists. According to him, it is absurd to think that the replica of a mountain, which is very big, could pass through the opening of an eye, which is very small. However, if the external agent is not a sort of “copy” of the object, he asked, then what could it be? For him, the answer was obvious: it came from the light. And so this is how he tried to convince the reader.

1. Objects send back the light that they receive

The first stage consists in showing that it doesn't matter which object it is, it is comprised as a source of light which it reflects in all directions. For this, he refers to the following experiment: "If a coloured object is placed in sunlight next to another object which is totally white and placed in a shaded area, then the coloured object appears on the surface of the second[5]." Ibn al-Haytham follows this up with the following explanation: "From the light coming from the body of the lit object itself (let us call this the primary or essential light) this gives off an accidental light from the surface of the coloured object as a secondary light to colour the white object placed in the shaded area" (see the diagram below). This phenomenon is not evidence of a common sense. In effect, the light that is resent by the objects, the "secondary" light to keep the terminology of Ibn al-Haytham is not visible and does not provoke, in general, any perceptible effect. In imagining that the lit objects act as light sources, Ibn al-Haytham realised a major advanced concept, the first in a long series.

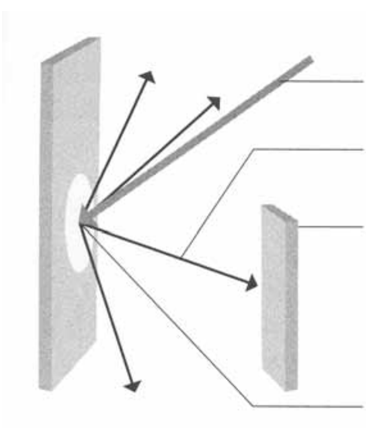
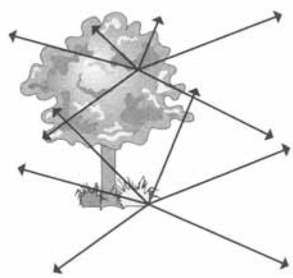


Diagram of the diffusion experiment as described by Ibn al-Haytham. The coloured object lit by the sun resends the secondary light towards the white object, which is then coloured itself.

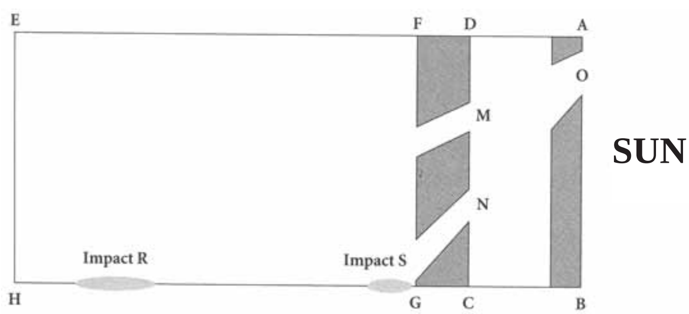
2. Light travels in straight lines leaving from a point of a lit object by itself or by diffusion

Ibn al-Haytham concentrates now on the characteristics of the journey of the light (do the lit objects emit the light by themselves or not) and refers to a geometric diagram. First of all, he has the idea to break down, no matter what the light source, all together from all points themselves lit from where is it emitted, according to the case, the primary light or the secondary light (see the diagram below).



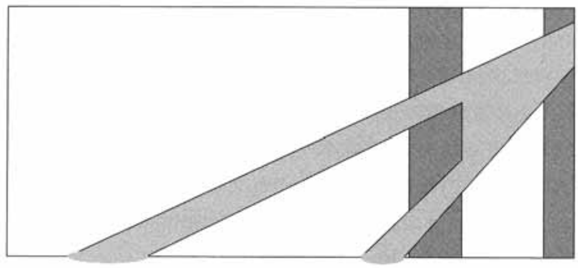
This tree, lit by the sun, is considered by Ibn al-Haytham as a whole of all the small light points from where the secondary light is emitted (here, only two points are considered). Note: in this diagram, the primary light is not represented.

Then, by a series of ingenious experiments carried out with the help of walls with holes in them, he demonstrates that light travels in straight lines. Let us consider the diagram below: A figure ABCD is lit by the sun thanks to a circular opening situated at O. This figure is separated by a second figure EFGH by a wall with two wide holes M and N (see the diagram). Two light beams R and S appear on the figure EFGH.



Representing a diagram of the experiment proposed by Ibn al-Haytham to demonstrate the rectilinear propagation of light (see Kitab al-manazir, book 1 chap3).

The form and layout of the light impact can only be explained by the fact that the primary light has created a straight line from the opening O, as well as the following figure.



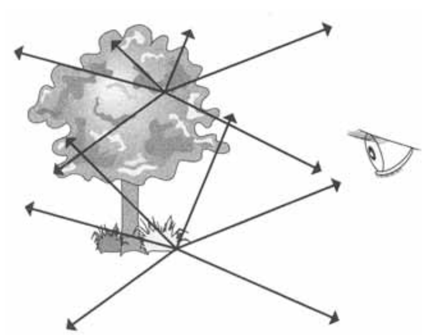
This formation can only be explained in so much as the light travels in straight lines.

3. Light has an effect on the eyes

It remains to show what effect on vision is produced when the eye receives secondary light emitted from objects that are lit. In fact, and also paradoxical, as this may appear, the phenomenon of being dazzled marks the departure point for Ibn al-Haytham's experiment. For him, if the light hurts the eye and damages the view, then this is a particular effect on the eye: "We have noticed that when the eye is fixed on an intense light, then it is hurt. Just the same, if an observer turns towards the sun, it is impossible for him to continually look without his eye being hurt by the sunlight [, ,]. All of which shows that the sun has an effect on the eye[7]." And this is the deduction that the light is the stimulus of sight, Ibn al-Haytham reasoned not only the light in itself, but also in its strength that objects (lit by themselves or diffusion) sends to the eye. He compares for this the effects of the light on those who are in pain: being dazzled causes pain in general quite alive and persistent. Oppositely, for normal vision, no treatment is needed. You can deduce therefore, in this case, the light does not attack the eye, and that it can stay on lit objects. For Ibn al-Haytham, he did not need to go further. Firstly, the objects that continually send out light that they receive and do not need a threshold from which the light received "would stay" on the objects.

Even though certain pains are bearable, the action of light on the eyes is perfectly bearable: “The effect of light on the eyes is just the same nature as pain. But all the same certain types of pain are unbearable, others, on the other hand, when they are weak, do not bother the organ in question. Such pains are not perceptible. A weak or moderate light does not make any pain, whilst a strong light causes pain. The only thing that changes is, more or less[7].” Otherwise he says, light can enter the eyes without us having to take it into account. In which case, it’s just that it comes in less strength.

Rectilinear propagation of the light, decomposition of lit objects as a whole from lit points, treatment of the strength of the light: in some pages, Ibn al-Haytham has made some revolutionary principles, against what was thought at the time and with a common sense, illustrated by a remarkable experimental method. It is from these principles that he has formulated an optical model of vision which will inspire numerous savants after him: “The lit objects emit, in all directions, light from the light that strikes their surface. When the eye detects a lit object, it focuses on the line of the light that leaves the object. And as the owner of the light is to affect the view and the job of the eye is to be responsive to the light, so the view occurs due to the light, leaving the object, going to the eye.” (see diagram below).



This is Ibn al-Haytham’s model for sight. The observer sees the tree as the light reaches each point of the tree, in strength not too hard or weak on the eye. No longer there, the primary light is not represented.

Ibn al-Haytham died in Cairo after 1040. His writing, known and translated in Europe from the XIII century, influences the works of European savants in the XIV and XV centuries, which reviewed his ideas and thoughts and thought greatly about them. In the XVII century, Kepler explicitly agreed with his optical principles and worked further on his theory of the formation of the image on the retina. The conceptual advances of Ibn al-Haytham therefore marks the start of a new era in optical matters, which became, with him, the science of light.

Notes

1. You often associate the Ancients with the discovery of "light rays" and the laws of light propagation. In fact, if Euclid and Ptolemy worked to establish the first laws of reflection, those concerning the modification of the journey of the substance emitted by the eye and not that of the "light", which was not defined as an independent object that could be displaced. By the pen of Euclid the "ray" became the geometric tool of looking, not that of the light. See on this subject, Gerard Simon, Le Regard, l'etre et l'apparence/ The Look, the being, and the appearance in the optics of Antiquity, Seuil 1988.

2. Aristotle, De l'Ame/ Of the Soul book II, 5-7. To see details sight according to Aristotle, see the work of Bernard Maitte, Une histoire de l'arc-en-ciel,/ A History of the Rainbow, Seuil 2005.

3. See about this Dominique Raynaud, La Sociologie des controverses scientifiques/ the sociology of scientific controversies, PUF, 2003.

4. Ibn al-Haytham, as all the Arab savants who are involved with optics, went to the ancient Greek school. This heritage is constituted in particular with the translation of l'Optique d'Euclide/ Optics of Euclide and the major part of l'Optique/ Optics attributed to Ptolemy, des Meteorologiques/ Meteoroliges and the treatise of Aristotle as well as the works of Galien on the anatomy of the eye.

5. Ibn al-Haytham, Kitab al-manazir, book 1, chap II.

6. Ibn al-Haytham, Kitab al-manazir, book 1, chap II.

7. Ibn al-Haytham, Kitab al-manazir, book 1, chap VI.

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4. Bernard Maitte, *Histoire de l'arc-en-ciel [History of the rainbow],* seuil, 2005.

5. Dominique Raynaud, Sociology of scientific controversies, PUF,2003.

6. Gerard Simon, *Le Regard, l'être,* et l'apparence dans l'optique de l'Antiquité [The Look, the being, and the appearance in the optics of Antiquity], Seuil, 1988.

How do we see the objects around us?
With the discovery of light

Objectives:
To see an object, the light needs to come from it and penetrate the eyes.
Ordinarily lit objects resend a part of the light that they receive.

Program reference:
“The sky and the earth: light and shade”.

Equipment:
Coloured cartons, pocket torches, shoe box.

In the XI century A.D., Ibn al-Haytham explains that for the first time in the history of science that, if you see it, it is because the objects around us are sending us, into the eyes, a part of the light that they have received. In recalling some of the experiments of the Arab savant, we recommend that you come along with Nabil and Fadila (see the child’s text), to the discovery of light and some of its properties.

Children and vision

When you ask young children “how do you see the objects around you”, most of them reply that if they see them, it is because the eye sends a “look”, “a sight”, “a view”, “something that takes the form and colour of the object”, briefly, an entity of nature fairly poorly defined, that, on leaving the eye, goes to meet the objects to be seen, copies their form, as if it was shaking hands. Even though these ideas are in the majority, one notes that certain children explain that if you see them, it’s because the eye receives the light following something from the objects. Others, even less in number, think that something comes from the object to hit the eye: colours, an image, the object itself. . . never the light! Certainly, all the children know, as Nabil, that without light you can see nothing. But its role is limited for them to light the object and that’s it (see below).

“The sun, lights the flower, and the person sees the things, to see with rays, and that allows him to see the flower” Geoffrey (5 years, Pasteur school, Bailly, 78).

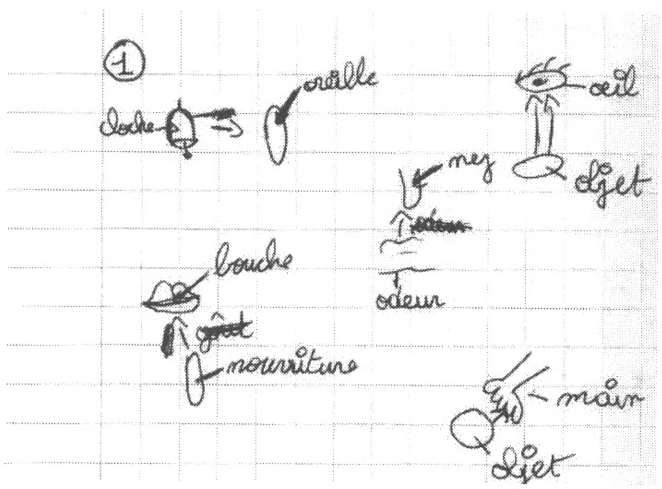
“The light lights the flower and the man sends a look at it” Frank (9 years, Karine, 67).

It is always interesting to know the way in which children explain a phenomenon. This portal allows us to determine which path to take, from the child himself toward knowledge (and not the other way around!) and to adapt his/her pedagogic act in consequence.

In this perspective, you can start by asking the children to explain how they see ordinary objects: a pen lying on a table, a rubber, their classmates . . . We are now going to offer them a series of activities to see if they can understand if it is necessary to look to see (in this sense, the arrow leaving the eye in the drawing has every reason to be there), it is also indispensable that the light coming from the lit objects penetrates the observer’s eye. For the purposes of the experiments the children are working in groups of four or five.

The five senses acting in the same manner

Aristotle was one of the first to have the idea that sight, as all the other senses, is the result of the reception by the eye of something coming from outside. This argument constitutes a starting point for our discussion. In effect, the children understand that if they hear, it’s because the sound comes to their ears; if they smell, it’s because odours come to our noses; etc. It is therefore possible to suggest to them that all the senses operate in the same fashion: its reception is the stimulus of a specific organ.



Drawings of a group of pupils of the Karine school at Strasbourg (67) in answer to the question: “Do you think that all the senses function in the same manner?” along with the following comment: “Ourselves, we think yes, because each part of the body receives something.”

In fact, a reasoning guided by the analogy of the question such as: “Do you think that all the senses function in the same manner?” leads them fairly easily to agree that the sensation is the result of a coming into contact of a sensorial organ with an exterior agent (see above drawing). What remains in question, however, is the identification of the stimulus of sight: “You know it for hearing or smelling, but for sight . . .”, a number of them say, that they are convinced of a unity of general functioning of the senses. It is therefore this sensation that we are going to help them to discover.

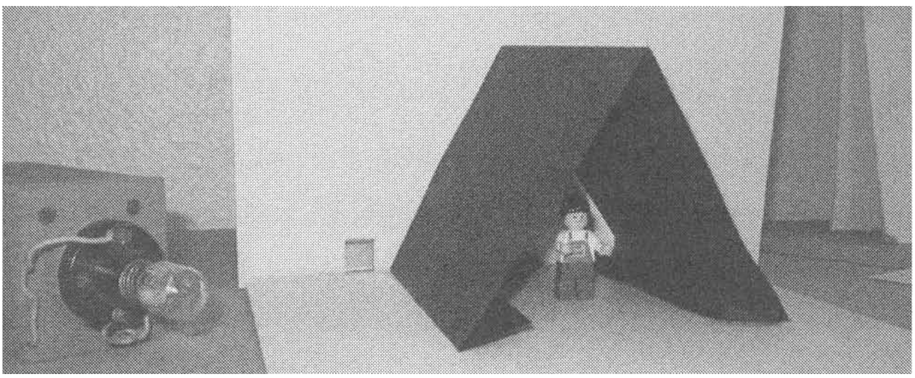
Light has an effect on the eye: the dazzling and the dilation of the pupil

On reading the children’s text, several questions remain unanswered: Why is Nabil unable to look directly at the sun? What does Fadila mean when she says there are “dark spots in the middle of her eyes”? We are concentrating on the pupil, this small hole in front of the cornea, a sort of diaphragm which regulates the amount of light entering the eye. The dilation of the pupil is easily noticeable. The following experiment proves this. The children are put into pairs, one opposite the other, in a darkened place, without light. At the precise moment when the teacher illuminates the class lights, the children noticed that the pupils of the eyes of their classmate opposite them reacted very quickly. At this stage, one should be aware of the reasons for this as stated by the children: the retraction of the pupil was not strongly associated with the entry of light in the eye, but to the simple fact that there was light in the room! The link with the entry of light in the eye can therefore be put down to being dazzled: “Is it really because Nabil is too young to look at the sun?” No, for sure, it is because he cannot cope with such a large quantity of light entering the eye. The children understand this easily. The pupil has the role of controlling the entry of light into the eye. This phenomenon is particularly noticeable with a cat.

But what link does it have with the vision of ordinary objects? To know this, we must construct the notion that the lit objects resend the light that they receive.

The objects resend the received light . . .

This phenomenon is called “diffusion”. It can be observed in lighting a coloured leaf in white light near to a white wall. When moving the leaf and the torch together one can see that the wall is coloured with the leaf's colouring: the light coming from the torch is resent by the coloured leaf onto the white wall which, in turn, resends this to the observer's eyes. Diffusion can be discovered by the children in carrying out experiments designed to answer the following question: How to make a white ball have one green side and one red side, whilst only using white bulbs?" The children get some coloured leaves, some pocket torches and a big plastic white ball. After some tries, they succeeded in making a red and green ball and understanding that the coloured leaves had sent the torch's light to the white ball.



You can make other experiments to demonstrate the phenomenon of diffusion. Each group of children were shown the photograph (above) (so that the light beam could be solely directed towards the front and to avoid any diffusion of the light, it is advised to cover the light with a sleeve of black paper). The teacher then asks: "If you put out all the torches apart from the room light, can you see the person in the tent? Why?" Many of the children thought that from the moment when the torch was illuminated, the person would become visible. Now, that's not right: when the torch is illuminated, it does not reach the person. This does not therefore send any light into the observer's eye placed in front of him. You then ask the children to find a means of seeing the person without touching the direction of the torch. Some decided to deflect the beam of the light with a mirror towards the person, others suggested using a piece of white paper. In fact, you can replace the mirror with any other screen, including a black screen (a black surface reflects at least 10% of its light)! The most amusing is to replace the mirror with your own hand or by different coloured screens. With the latter, you can systematically ask the children:" What will happen when I interrupt the beam of light with a sheet of paper coloured blue, red etc.?" The lit objects therefore reflect the light. Even the person in the tent. In effect, if the light comes back with the colour of the paper that are interrupting the light beam or from the mirror, there is no reason that it should be stopped from reaching the person! However, perhaps, the "something", coming from the objects, hits the eye, and makes you see it.

. . . and you see when the light penetrates the eye

However there is still quite a few to be convinced. In effect, many of the children do not understand that the light enters their eyes only if they can feel it doing so. There is a threshold for them to understand how the light comes back from the lit objects. This threshold is subjective; it corresponds to the moment when their sight is no longer feeling the effect. Now, when the sight is operating without pain (which is most of the time), the light penetrates the eye to a lesser amount. It is the same for hearing: if there is a deadening sound it is disagreeable, but a moderate sound is ok. So here we can lead the children towards the idea that the eye continuously receives light from lit objects, even when you are not noticing them. The analogy with hearing can be a good point to leave this, especially if it is raised properly during the first stage.

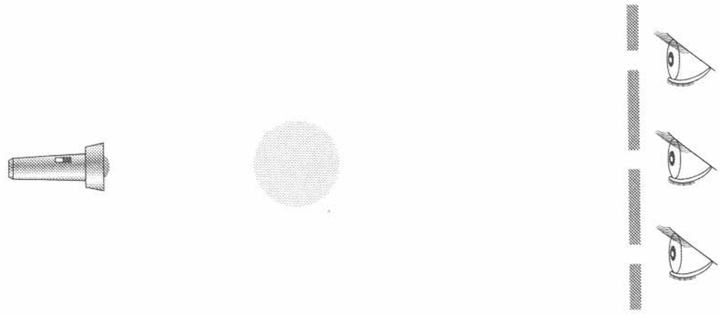
The children know now that if they see, it is because the lit objects send some light into their eyes. The explanation takes them step by step along the intellectual path of learning. They would be well advised at this stage to use a sequence as a synthesis document. Nevertheless it is normal for them to characterise certain of the properties of the light, especially its invisibility and its rectilinear trajectory.

Light is invisible "in profile"

For the majority of the children, the light appears from tenable sources such as torches, lamps, the sun, candle flames or from its impact on visible objects. Also they are thinking that they could come to the light when it was happening next to them. Linked to this certitude, they often remember that when the beam of a laser or the car headlights are visible at night (what is visible, are in fact suspended particles in the air, particles of dust or fine droplets of water. These particles are reflecting the light back into the eyes of those that are looking at them). We suggest to them, therefore, to devise an experiment that would permit us to know if the light is visible "in profile" or not. Some pupils suggested closing the classroom shutters and looking at the light coming through the gaps in the shutters. Result: no trace of light is visible in the classroom. Other suggestions were the construction of a box which allows the "trapping" of the light. This was done with a shoe box, the interior of which was painted black and it was holed. Each hole has a tube and, on the side of the box, a little window is cut out. Then a pocket torch was lit and placed at the end of one of the tubes and you could look through the window to "see" the light passing. Now, having carried out the experiment, the children deduced that one more time, you could see . . . . . nothing! Some of them suggested placing a white object at different points in the box and to look again through the window: whilst the object was clearly visible as it was placed on the trajectory of the light (it resent the light that is received by the observer's eye), it remains invisible if it is found outside of the beam.

Light acts in a straight line

Now we wish to examine the trajectory of the light. Some of the children invited the teacher to take the black box from the previous experiment and light the torch whilst leaving the lid off. This proposition started off a lively debate at the heart of the class: some of them held it would not give any indication as to the trajectory followed by the light, as it is invisible. Effectively, no deduction was possible from this experiment.



We suggested to two children to think together about the following situation: a white polystyrene ball lit by a torch. A screen with three holes in it is placed on the other side of the ball. A diagram of the experiment can be referred to (below). After the drawing is passed out by the teacher, the children are going to find out what will come through the holes when the torch is switched on. Putting the drawings together allows them to notice the diversity of the representations of the propagation of the light, often traced curved, bypassing the objects placed on its path, and rarely rectilinear. In fact, the experiment allows them to note that the light source is not visible apart from the higher and lower holes. Since the middle hole sees the ball's shadow. The conclusion for most of the children with the experiment is to modify the drawing. Some think that there is a rectilinear propagation of the light. At this stage of the activity, the children note that a shade is an area that does not receive light (or receives little) light. This is the case with the shaded area visible behind the ball at the middle hole level: the eye placed behind the middle hole does not receive the torch's light. It is the reason why this area, seen from opposite, appears darker. We rely on this to understand the formation of "shaded colours" (see the chapter on the rainbow).

Therefore, if we see the objects around us, it is because they are resending into our eyes a part of the light they have received. This light is certainly not visible, but you can represent its trajectory in straight lines, then, precisely, it travels in straight lines as long as it does not encounter an obstacle. The pedagogical course suggested here is made with reference to the genius of a savant Arab, who did it in the XI century, the first one to start to develop true experiments.

The favourite game of Nabil and his sister Fadila was to explain the things that occurred around them, the things that they observed around them or in them. They were therefore passionate than others of their time, a little magic mingled amidst them, like the day when they wanted to solve the secret of light . . .

That day, Nabil and Fadila had just set up a tent by the river bank. They had made it from an old green curtain, so that they were protected from the sun, and were hidden from view in the middle of the papyrus. They were observing the countryside that they could see through a little opening, until Nabil asked his sister:

— Fadila, how can that big palm tree on the opposite bank of the river completely enter our tent so that we can see it with our eyes?

— Our eyes send it perhaps something that transforms it into a traced image, firstly until it enters the tent, then until they. . .

Fadila interrupted. She looked at Nabil; it appeared to her that he had turned green.

— Nabil, do I look green to you, me as well?

— Yes, it is strange, look, even our clothes are not the same colour!

He stretched his hand outside and, by the light of the day, it retook its ordinary colour. He raised his eyes to the sun, but the pain forced him to desist and go back in the tent, angrily. Fadila mocked him:

— Nabil, if you could see your head, everything is green again! Why are you so furious?

— Because I cannot look directly at the sun!

— It's because there are black spots in the middle of my eyes, which are not becoming any smaller. We are too young and our eyes have not yet learned how to do it!

Nabil did not appear convinced, besides he had not seen any adults looking directly at the sun. Fadila changed the subject to deride her brother:

— And at night, you know that you can see clearly without becoming a cat?

—If that's right, I would like to become a cat. The black circle in the middle of my eyes would be a fine line during the day and a big circle at night, and my eyes would shine so that I could see everything!

Nabil was smiling again but he was, as was Fadila, frustrated as their questions remained unanswered. It was then that a light wind blew inside the tent and a man with a white beard, wearing a turban and a long brown coat sat next to them:

— Hello, I am Abu Ali al-Hasan ibn al-Haytham. I have been listening to you for a short while and I believe I can help you. Return here at the same time tomorrow, and I will help you to enter into the secret of the light, as I discovered it a long time ago.

And the man disappeared as he came, with a puff of wind, inexplicably. Nabil and Fadila took down their tent and papyrus ties and returned home, impatient for the following day.

What happened the next day is not known to us, it was so long ago, the memory is lost! All we know is that Ibn al-Haytham was the first to know the secret of the light and how our eyes see. And in one manner or another, just as he previously visited Nabil and Fadila, he visits us today and everyone that asks the same questions. In one way or another. . .

Pulmonary Circulation

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The discovery of pulmonary circulation by Ibn- al-Nafis

It was in the XIII century, in Cairo, that Ibn al-Nafis wrote, for the first time, pulmonary circulation, which opens up the road for the discovery of the blood circulation system, it completely transformed medicine.

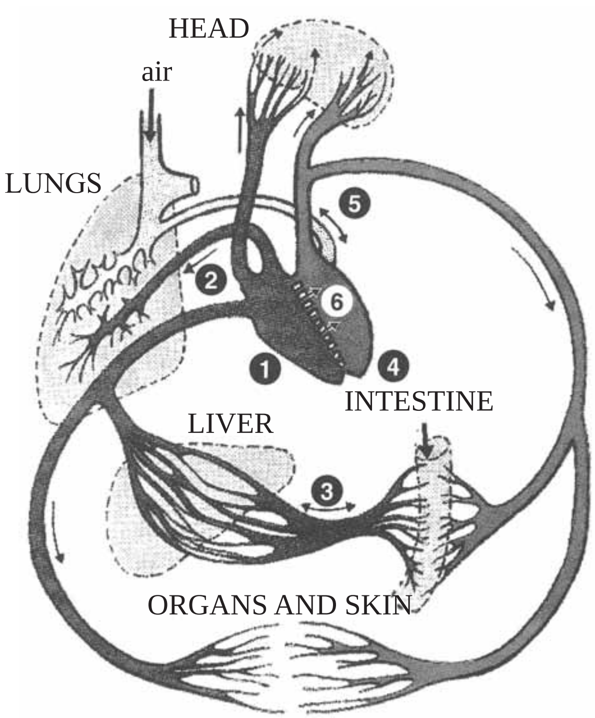
Ibn al-Nafîs was born at al-Karash, near Damascus (Syria), about 1210. He did his medical studies at the al-Nûrî hospital, which had an excellent library. His master was Muhyî al-Dîn al-Dakhwâr, known for his work in ophthalmology. He worked first in Damascus then, when he was about thirty, he moved to Cairo at the invitation of Sultan al-Kâmil to work at the al-Nâsirî, reputedly the best hospital in the Orient. There he was joined by numerous students and became the head doctor. In 1284, he left this hospital to direct the new al-Mansûrî. He died in December 1288 at Cairo, having left his possessions and his library to this hospital.

Ibn al-Nafîs was everything: a doctor, a philosopher, linguist, and jurist. Loving science he organised at his house, debates for groups of doctors, philosophers and theologians and distinguished himself with a great knowledge and great independence of spirit. A talented author, he wrote philosophical and theological works as well as medical treaties, notably the *Kitâb al-shâmil fî l-sinâ'a al-tibbiya (a complete medical book)* that he was supposed to write in three hundred volumes, but could only manage eighty. Ibn al-Nafîs commentated on the books of Hippocrates as well as Canon of Avicenna that he made in two works, the first, the *Mûjaz fî l-tibb (medicine abridged)*, dealing with the practice of medicine, the second, the *Sharh tashrîh al-Qânûn (Commentary on the anatomy of Canon),* dealing solely with anatomy. It was the first work to deal with this autonomous branch of medicine. Gifted with a sharp sense of observation together with a creator's doubt, Ibn al-Nafîs believed in the facts as he perceived them. "Anatomy, he wrote, is an art and not a science and the art is acquired by practice just as science is acquired by study." He also said, that to acquire knowledge solely through the books of the Ancients was far from being enough. These are the qualities that allowed him to transgress the dogmas of his time in the matter of the circulation of the blood, which have been apparent for a thousand years, and to know the role of the lungs in the circulation.

For the Ancients, the heart was formed from two very distinct compartments, a right ventricle and a left ventricle separated by a septum. The auricles were not considered as parts of the heart but as kinds of vestibules extending the afferent veins: to the right the "vena cava", formed by the auricle and the terminal part of the four pulmonary veins. They would have considered therefore that the "vena cava" and the "pulmonary vein" were in direct relation to the corresponding auricular - ventricular orifice.

For Galien, the right ventricle was in relation to the veins which contained the blood that they distributed to the organs to feed them. In this system, the blood cannot fully reach the lungs. The pulmonary artery, in relation to this ventricle, was considered as intervening in the nutrition of the lung and by consequence as a vein. The vein door led the intestinal chyme (concentrated main food drawn into the digestive tube) to the liver where it was transformed into blood, intervening also in the nutrition of the digestive tube. It was, from this fact, the seat of the circulation of blood and chyme in two opposing senses. The left ventricle was in relation to the arteries. A sort of heating, this ventricle was the seat of an inner heat partially cooled by respiration. It generated the vital pneuma, or breath (or even spirit), leading the developed air to leave the heat of the left ventricle to make contact with the air coming from the lungs by the pulmonary vein and a small

Blood circulation according to Galien



1: Right ventricle
2: Pulmonary artery *[arterial vein]*
3: Vein door
4: Left ventricle
5: Pulmonary vein *[veineuse artery]*
6: Interventricular septum pores

quantity of refined blood which travels through the interventricular septum). To explain this passage of blood through the interventricular septum, Galien imagined the existence of pores communicating with the two ventricles. The breath generated in this left ventricle and blood reached this ventricle was diffused by the aorta to all organs, including the heart, for them to transmit life and moderate warmth. In this system, the pulmonary vein was considered as an artery, called “veineuse” by virtue of the slimness of its wall. Given that it carries the air to the left ventricle and the breath to the lungs, it was the seat of circulation, in two opposing senses. As to the arteries and vein systems, they both drive the blood towards the periphery where it dries out under a form of transpiration. From this fact the blood and the breath are constantly renewed.

Some doctors and philosophers of Islam countries who preceded Ibn al-Nafîs, such as al-râzi (Rhazes), aal-Mâjûsî (Haly Abbas), Ibn Sînâ (Avicenna), al-Zahrâwî (Abulcassis) and Ibn Rushd (Averroes) have all advocated this theory. They have been essentially compilers of anatomical material. Their contribution to this discipline has been fragmented, such as the description by al-Mâjûsî of passages communicating with the ramifications of arteries and veins, prefiguring the notion of capillary circulation. As Galien, they explain the organ structure by their uses, that is to say by the hypothetical physiological data adapting the morphology of these organs with their physiological vision.

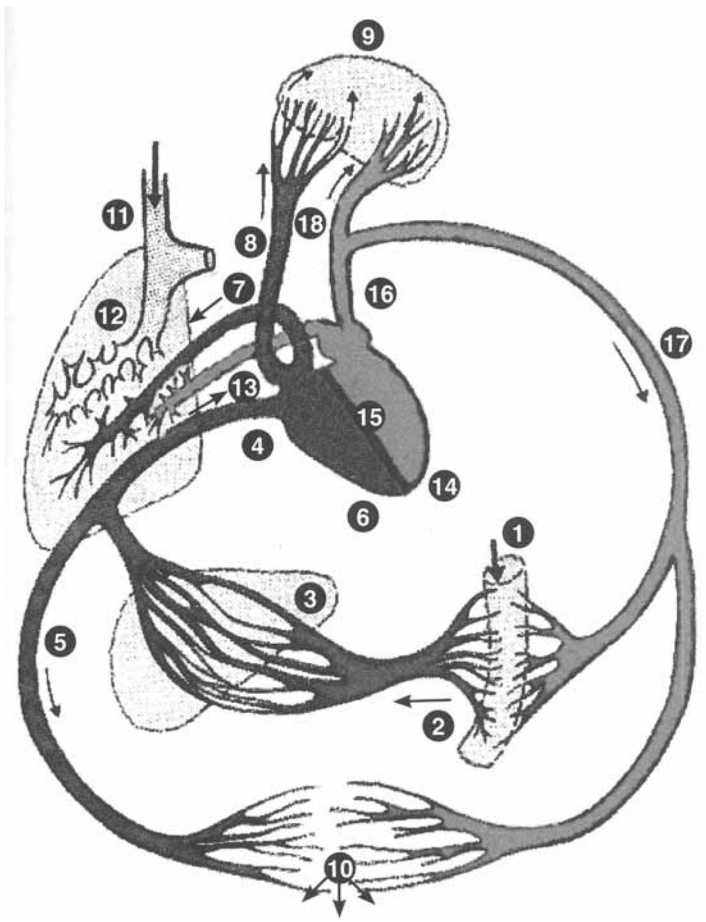
You have to wait until the XIII century until Ibn al-Nafîs refutes Galien’s theory and proposes a schema where the blood travels to the lungs before reaching the left heart and, from there, the arteries. Here’s what he wrote: “Once the blood has been refined in the right hand cavity of the heart, it has to be passed to the left cavity, there it mixes with the breath. Now there is no passage between the two cavities for the composition of the heart as this place is dense, not being made up of any apparent passage as was commonly thought, nor any unapparent, which would allow the voyage of the blood as was imagined by Galien. The heart’s pores at this place are closed and the substance of the heart is thick. Also, once refined, the blood must pass the arterial vein [pulmonary artery] to the lung to become widespread in its mass, to mix with the air, to purify its fine part then to penetrate the veineuse artery [pulmonary artery] which drives it to the left cavity of the heart. This blood mixes with the air and is ready to generate the breath. The remaining blood which is less refined is used for feeding the lung.”

Ibn al-Nafis defines the structure of the lungs as being formed from branches, from ramifications of the pulmonary artery and from ramifications of the pulmonary vein, everything wrapped in slack and porous skin. It possesses the haematosis mechanism (enrichment of the blood with oxygen with loss of carbon gas): “The air only becomes useful to nourish the breath if it is mixed with the constituents of the blood to form a constituted combination of the air and its constituents [. . .]. The rest of the air which has been reheated and which is not useful to regulate the breath needs to be expelled in order to make way for the air which enters after it, be it isolated or mixed with very fine particles of blood. It is conveyed to the lung to be expelled in the course of expiration.” This is in opposition to the inverse sense: “To say that the veineuse artery [pulmonary vein] conveys the blood from the heart to the lungs which feeds the lungs straight away is wrong. The feeding of the lungs is not done by this artery [vein pulmonary] for the blood of this artery does not re-enter the left cavity of the heart towards the lungs given that the blood that is in the left cavity comes from the lungs and not that the lungs raise it in the left cavity. As to the passage from the heart to the lungs, it is done by the arterial vein [pulmonary artery].”

Also, Ibn al-Nafis’ contribution in the sphere of blood circulation can be summed up by these six points:

1. He denies the existence of a blood passage from the right ventricle to the left ventricle through the interventricular septum;
2. He considers that blood arrives at the lungs through the pulmonary artery not so much as to nourish them but to load the air and rejoin, by the pulmonary veins, the left ventricle where, according to the thoughts of the era, it forms the breath;
3. He defines the cardio-pulmonary circulation as: the blood from the right ventricle should arrive from the pulmonary artery to the lungs, spreads around

Blood circulation according to Ibn al-Nafîs



1. Intestine
2. Left vein
3. Liver
4. Vena cava (ascending)
5. Vena cava (descending)
6. Right ventricle (right heart cavity)
7. Pulmonary artery (arterial vein)
8. Jugular vein
9. Encephalon
10. Organs and skin
11. Trachea
12. Lung
13. Pulmonary vein (veinous artery)
14. Left ventricle (left heart cavity)
15. Interventricular septum
16. Aorta (ascending)
17. Aorta (descending)
18. Carotid artery

their area, combines with the air that comes in through the branches, is purified, penetrates the ramifications of the pulmonary vein by the "perceptible passages" that exist in the lungs between these two vessels and reach the left ventricle;

4. He refutes the existence of a circulation in both opposing senses in the pulmonary vein and in the left vein;
5. He had a premonition and imagining the exchanges between the drained blood by the pulmonary artery and the air led by the branches to the alveoli in the lungs by "the combination of certain fine blood particles with an aerated structure contained in the drawn in air". These "fine blood particles" were identified in the XVIIIth century by Lavoisier as being haemoglobin and oxygen which had combined to form oxyhaemoglobin;
6. He also said that the air that was not used to generate the vital breath is exhaled to make room for new air. We know since the exhaled air leaves carbon gas deposits in the tissues.

One wonders if Ibn al-Nafis only formulated a hypothesis that is exactly revealed or if he bases it on a detailed anatomical knowledge. The lecture of *commentaries on the Canon's anatomy* lets us conclude that his new ideas come from a physiological reflection founded in his anatomical knowledge. When he confirms that the interventricular septum does not make any apparent or unapparent communication, his determination gives the impression that he had minutely examined this septum. Sure about his convictions, Ibn al-Nafis is opposed to Galien and Avicenna who held, for example, that the diaphragm was perforated by two orifices of which the larger gives passage to the aorta and the oesophagus. It corrects them with a great assurance: "The aorta does not need to perforate the diaphragm to travel through it for it lies in its part of the diaphragm at the 12th dorsal vertebrae, that is to say that it passes behind the diaphragm and leans against the rachis bones [. . .]. I have often noted the opposite of what they have observed several times in the course of their dissections." Such an affirmation leaves no doubt to the fact that Ibn al-Nafis is not happy with the reasoning but was enriched by the experience, otherwise he said that he proceeded with human anatomical verifications

Remember that in this era, although this practice may have never been expressly forbidden by the Koran, human dissection was considered by the theologians as a sacrilegious profanation.

In the XVI century, Padua renewed the rational logic of Aristotle through the writings of Arabic philosophers. The complete translation of Avicenna's *Canon* appeared in 1527. The 1547 edition, published in Venice by Paolo Alpago, contained a critique, by Ibn al-Nafis, of Galien's doctrine on the heart and arteries. Also, Ibn al-Naifis' ideas circulated among the anatomists certain of whom were inspired in their works, without quoting him. Michel Servet inserted the description of pulmonary circulation in a religious work, *Christianismi restitutio, restitution of Christianity* that he published in 1553, and for nearly four centuries he was accredited as the discoverer of this circulation.

Numerous witnesses confirm that the doctors of Padua's school, in the XVI century, knew the works of Ibn al-Nafis and were inspired by them. Francesca Luchetta, in a work on Andrea Alpago, taught us that the latter was done in 1487 at Damascus as the Venetian consul's doctor, that he had been initiated into the nuances of the Arabic language and to the study of manuscripts and works of medicine and philosophy of an Arab doctor and philosopher, Chems Eddine Ibn al-Makki, whom he had called his "master". After a stay of more than thirty years, he returned to Padua in 1520, taking back with him a rich harvest of Arabic manuscripts and works, of which he had translated certain ones into Latin, amongst them were the writings of Ibn al-Nafis. After his death in 1522, his nephew, Paolo Alpago disributed these works.

In 1598, William Harvey came to Padua considered as the capital of anatomy in Europe, to follow his medical training that he had started in Cambridge. In 1602, he received his doctor's degree in medicine. Here's what can be read in his *journal [Diary]* (established by Professor Jean Hamburger in 1983): "I was overtaken by a greyness all of a sudden, I knew that the blood circulation had given me its secret [. . .]. I found myself at Padua and I was twenty eight years when the event occurred [. . .]. And soon, I ought to discover that in these walls and in these streets of Padua, a fascinating red-hot spirit. I have never experienced such precious influences of famous professors as my dear Fabrice d'Acquapendente. It is necessary to understand how he had discovered the vein valves that, on the interior of these vessels, seemingly to prohibit the blood from going to the extremities. If I had stayed in England, if I had not understood my dear Fabrice speaking abundantly, I would have missed an essential point in my researches."

The discovery of blood circulation by William Harvey in 1628 has therefore been preceded by the works of two eminent initiators, who have for a long time stayed in the shade. Ibn al-Nafis who, in 1240, had written the pulmonary circulation and presented the mechanism of haematosis, and Fabrice d'Acquapendente who, in 1560, had put forth evidence of the role of vein valves, which have definitely fixed the orientation of the vein blood directly towards the heart and not via the "extremities".

One can conclude that the discovery of blood circulation has been an anatomical and physiological Greek – Arab – Western construction achieved in stages. Benefiting from previous knowledge, Ibn al-Nafis had the idea of re-examining the ideas of Galien which had prevailed for the last eleven centuries and to tackle the question of blood circulation in a realist sense, which opened up the road to fresh research. Taking notice of the passionate debates and controversies undertaken by Padua's anatomists about this question, William Harvey demonstrated, by rigorous experimentation, that blood circulated in a closed vascular system, that is distributed by the aorta to the whole body, that come back via the vena cava to the right heart then to the lungs to revive before passing into the left heart and recommences its cycle. This is what is given to the system of blood circulation as its definitive form, to be given as the basis for modern cardiology.

Bibliographic references for this text figure in the foreword of our French translation of the *Commentaire de l'anatomie du Canon d'Avicenne par Ibn al-Nafis /,Commentary on the anatomy of Avicenna's Canon by Ibn al-Nafis* Tunis, Simpact, 2005.

“My blood only goes round once” The discovery of pulmonary circulation

Pre-requisite in year 3 primary school: a first approach to respiration in the field “Human body and health education”.

Objectives:
Year 3
— To know the role of the circulation in the nourishment of organs;
— To know the anatomical relations between the circulation and respiratory systems;
— To learn the inherent risks of tobacco addiction, alcohol consumption and drug use.

College, fifth year
— To understand that blood circulates one way in the vessels, which form a closed system;
— The role of the heart in the movement of blood.

Reference to the science and technology programme of year 3 in primary school:
Human body and health education (first approach to blood circulation).

Reference to the science of life and earth, college (year five):
Functions of the organs and energy needs: the role of the heart in the well being of the organs.

Equipment list for a class of 25 to 30 pupils:

Chronometer, transparent plastic tube fairly long (50cm), syringes, vinyl gloves, straws, medical case with 4 stainless steel instruments for dissection (small and large pincers, scalpel, pair of scissors), 2 hearts-lungs, 15 lamb's hearts in a good state with 2 cm of blood vessels (so that you can insert the plastic tubes) – to be ordered from the butchers-, 2 white basins (to see the blood better), some sponges.

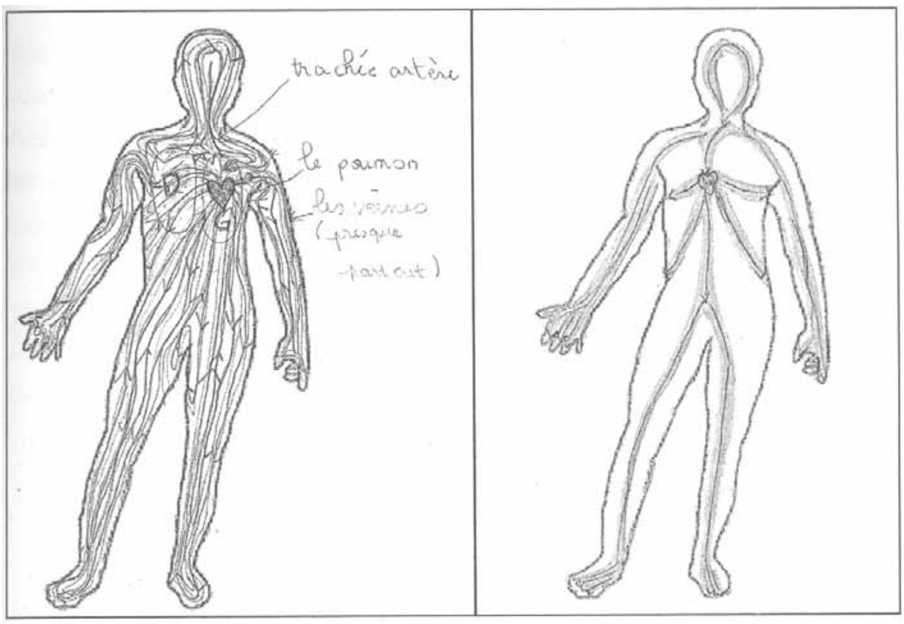
About the II century A.D. the doctor Galien proposed the idea of the journey of the blood in the heart which was held until the XIII century. According to Galien, part of the blood which was in the right of the heart served the lungs, the other part was to eliminate substances produced by the body. A little of the blood contained in the right cavity of the heart also passed into the left cavity via the septum which separates the two halves of the heart.

This idea will be reinvestigated, about 1230, by Ibn al-Nafis, medical surgeon at Cairo. Ibn al-Nafis also put forward another proposition: the blood leaves the right cavity of the heart to go to the lungs, but returns to the left heart cavity, without going through the septum. It was not until the XVI century that the blood's journey between the heart and lungs, described by Ibn al-Nafis, will be "rediscovered" in Europe, by Servet and by Colombo. In the XVII century, Harvey latched onto the idea of the blood flow between the heart and the lungs to construct his circular model of the blood's journey between the heart and all the organs.

This brief historical memory illustrates at what point the anatomical education was at, or how little was known, on the real function of the organs, for the same anatomical facts can be interpreted differently. We propose, here, to discuss some of the pedagogic measures to examine the thesis of Ibn al-Nafis and Galien, and to show why Galien's idea was abandoned in favour of Ibn al-Nasfis's.

Children’s representations when faced with scientific notions

Children have their own ideas on the voyage of the blood in the body. This comes from irrigation, such as water overflowing in garden ditches, the idea of the distribution of blood leaving from a central organ (generally the heart), or circulation in the sense of a closed circuit. The children’s drawings represent quite well the “tubes” in a network in which the blood is canalled, but not necessarily in movement, that the tubes are re-linked to the heart and sometimes the lungs.



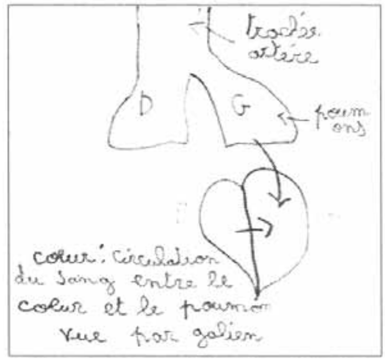
Representations on the blood’s journey in the body

Lice’s drawing (CM2, Joliot-Curie school, Montreal)

Aurore’s drawing (CM1, Joliot-Curie school, Montreal)

The difference between the ideas “spontaneous” and historical theories of Galien and Ibn al-Nafis, allows us to discuss, in class, some questions: what does Galien say? What does Ibn al-Nafis say? Is it the blood that moves? Does it move in all senses or just one, what is the journey of the blood in the heart and in the body, etc.?

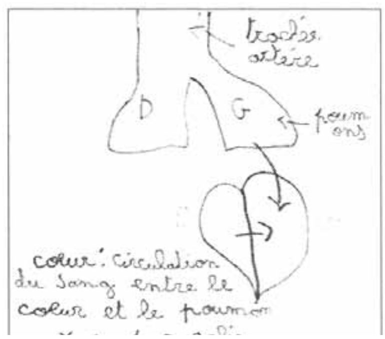
Galien's theory



Sarah's drawing
(CM1. Joliot-Curie school, Montreal)

According to Galien, a part of the blood contained in the right part of the heart goes through the septum by its small pores (not visible to the naked eye) to the left part. The inhaled air coming from the lungs passes directly into the left heart.

Ibn al-Nafis theory



Kevin's drawing
(CM1. Joliot-Curie school, Montreal)

Ibn al-Nafis thinks, contrary to Galien, that the lungs contain some blood; that this comes from the heart and returns there by two different ways: "There is no passage between the two cavities [right and left] for the substance of the heart here is compact, not comprising the apparent passage as it is commonly thought of, nor the unapparent passage which allows the blood to go through as Galien imagines. [. . .] Also, once refined, the blood must pass by the arterial vein [pulmonary artery] to the lung to spread out, to be mixed up with the air, to purify its fine part then to penetrate the veineuse artery [pulmonary vein] which leads it to the left of the heart."

How to establish a functional link between the heart and the lungs?

For many children, the heart and the lungs have two separate functions:
- the heart for turning the blood in the body;
- the lungs to breath.

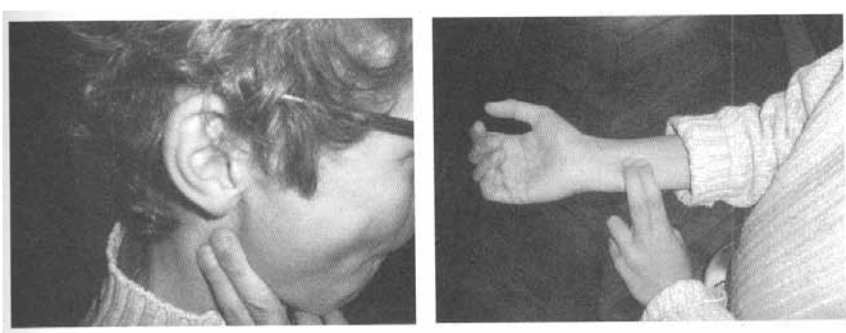
Ibn al-Nafis wondered how to check to see if there was a possible link between the two organs?

The lung is known as the respiratory organ, assuring the entry (the inhaling) and the exit (the exhaling), whilst the heart is the organ that contains the blood. Also some children emphasise the link between breathlessness during physical effort and the acceleration of heartbeats: "If you run for too long, the heart beats very quickly, too strongly and it is difficult to breathe." A means of co-relating between breathing and cardiac activity is to measure the frequency of breaths and of heartbeats, to rest and after an effort.

Measuring the frequency of the heartbeats

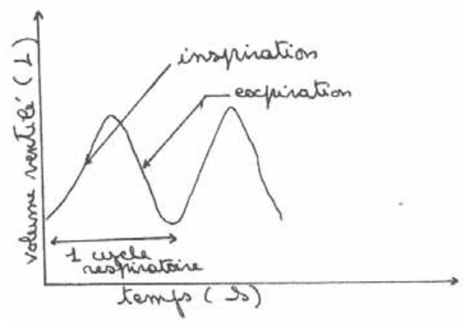
This can be done by taking the pulse: you just have to place your index and big finger on the radial artery (the underside of the wrist) or on the carotid artery of the neck (to the left or right of the larynx, under the lower jaw). These pulses correspond to the propagation, in the wall of the artery, one beat is equivalent to one heartbeat.

The frequency of the beats corresponds to the number of pulses per minute. Each beat represents the number of pulsations per minute, at rest and after physical exercise (after twenty press-ups for example).



Measuring the respiratory frequency

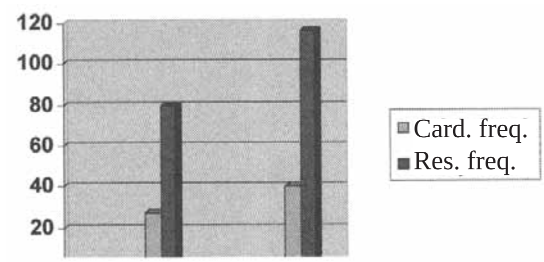
You have to count the number of respiratory cycles. Each cycle constitutes one inhalation and one exhalation. The frequency is therefore how many respiratory cycles per minute. Here again, this is done during rest and then after physical exercise (just the same as for taking the pulse).



The data has been put into a graph form to obtain an average.

Activity	Rest	Physical Exercise
Respiratory Frequency	26 27 28	40 42 40
	Average = 27 cycles / min	Average = 40.6 cycles per/min
Cardiac frequency	80 90 70	120 120 110
	Average = 80 pulses	Average = 116 pulses /min

Results in the form of a bar graph.



The frequencies – cardiac and respiratory – vary accordingly in the same manner, from rest to effort. The children therefore expect to research an explanatory link between the two.

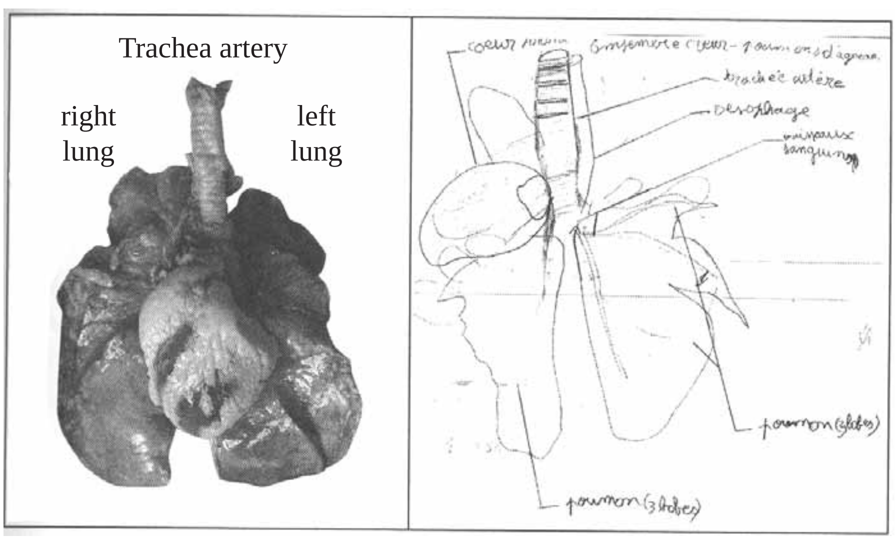
For the majority of the children, the inhaled air passes into the lungs where it transforms itself into expired air, without mixing with the blood. A return to the theory of Ibn al-Nafis makes us examine why there is a presence of blood in the lungs. How to prove it?

Is there blood in our lungs?

In order to verify the presence of blood in the lungs, the children observe, and touch and cut into the lungs. A heart and lung together, preferably from a sheep, is used for this (it is necessary to examine at least two of the pairs one is used to compare with the other one that has been physically examined).

Observation with the naked eye allows us to discover two lungs formed from three lobes and the presence of two types of "tubes": those that are hard to the touch with rings (trachea and bronchi) and those that are smooth (blood vessels).

To verify that the air enters and leaves from the lungs, the children suggest blowing in the trachea (it is however, preferable to use a syringe).



The heart – lung together (external view). This is a sheep's heart and lung together – the general organisation of the cardio-respiratory apparatus of the sheep is similar to a human's. To help the children understand that the left half of the heart and the right half are inversed, as we are seeing them head on, it is interesting to show them an x-ray of the thorax (head on and in profile), which allows them to site exactly the heart and the lungs and to draw them from a head on view, full of air to breath, that is to say to exhale a certain quantity of CO_2. Using a filling pipe inserted into the trachea, and pinching it to keep the air in, the children blow in it. The lungs inflate and become whiter. The lungs that the children have not blown in stay red and do not get any bigger. As to the heart, it is not affected in colour or in volume. This shows the entry of air into the lungs via the trachea, but it has not left. Making a comparison by touching both the inflated and non-inflated lungs, one notes the first one has a granular aspect with bubbles which click under the fingers, whilst the second remains soft. Some transverse cuts of the inflated lungs and non inflated of 2 cm, place them in a basin filled with water for an observation aide, for the inflated lungs, there are some small blood clots and bubbles and as to the non inflated, there are some blood clots but no bubbles.

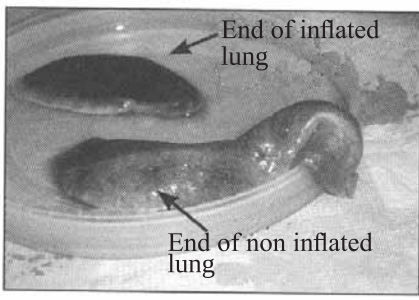
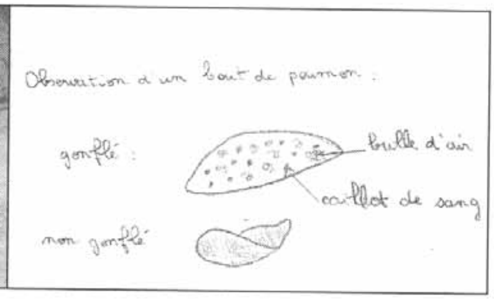


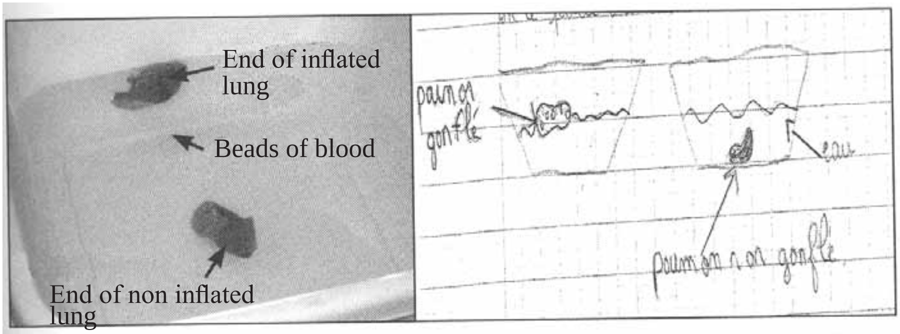
Photo Nadia Ouahioune
(End of inflated lung)



Drawing by Lice
(CM2, Joliot-Curie school, Montreal)

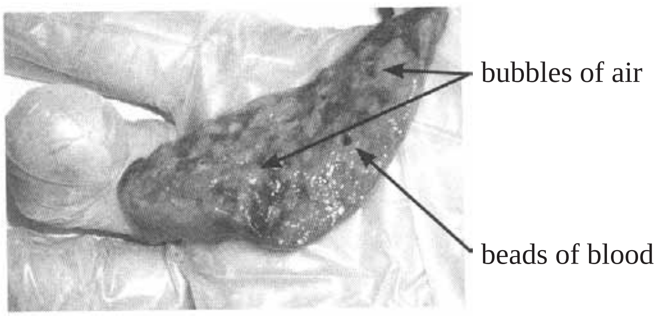
Some of the children make an analogy with their bath time and the "release" of gas!

The piece of inflated lung floats whilst the end of the non inflated lung bends at the bottom of the basin. To their great surprise, the children notice that the beads of blood escape from pieces of the lungs. The origin of the bubbles is explained by the children due to the presence of the "tubes" for the air, and that of the blood by the presence of the other "tubes". They press the lungs to chase the air and the beads of blood.



Pieces of inflated lungs inflated and non inflated plunged in a basin of water

Photo Nadia Ouahioune *(End of inflated lung)* — Drawing by Lice (CM2, Joliot-Curie school, Montreal)



Therefore, the children distinguish the “tubes” that carry the air (trachea and bronchi) and the “tubes” that carry the blood (blood vessels).

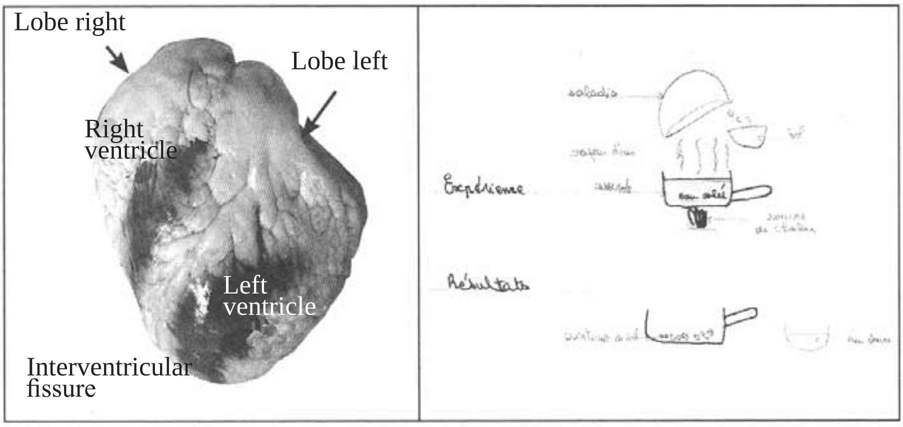
A return to the observation of the heart-lungs together is going to let us visualise the anatomical connections between the heart and the lungs and to investigate the journey of the blood between the two organs.

What is the journey of the blood between the heart and the lungs?

At this stage of reasoning, it is important to return back to the theories of Galien and Ibn al-Nafis to retake their hypothesis on the journey of the blood in the heart.

From Galien, the interventricular septum is permeable, the blood travelling there from the right cavity towards the left cavity by the small pores.

From Ibn al-Nafis, the interventricular septum is impermeable. The blood leaves the right cavity of the heart in order to rejoin the lung and comes back to the lungs by the left cavity of the heart.



Sheep's heart looking at the ventricle

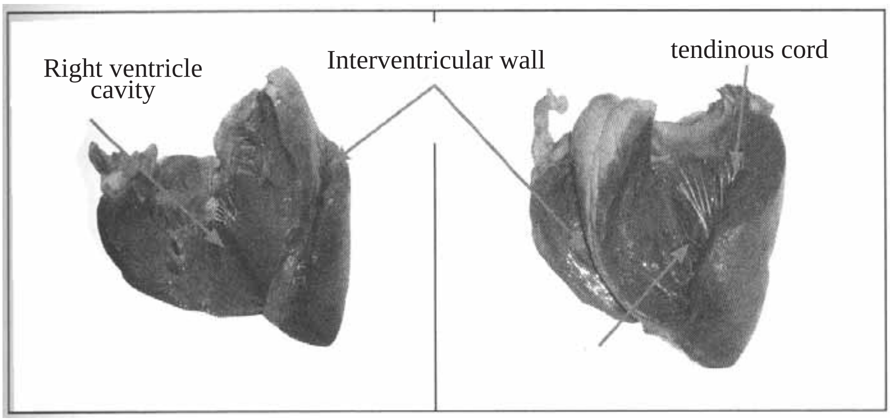
Photo Didier Pol, Multimedia — Drawing by Lice (CM2, Joliot-Curie school, Montreal)

So that we can test these two hypotheses, we should return to the ventral and dorsal look at the heart: the ventral aspect, to the inverse of the dorsal aspect, there is a slanting interventricular fissure and it is bulbous. The interventricular fissure indicates the course of the septum's separation between the right and left halves of the heart. With the help of straws inserted in the blood vessels, it is possible to notice that the heart is provided with:

- four cavities: two lobes and two ventricles;
- two types of blood vessels on the main part of the heart: the arteries, to the white rigid wall, and the veins, to the red smooth wall. The arteries designate the vessels containing the blood which comes out of the heart, and the veins that contain the blood which returns to the heart.

How to test Galien's theory?

In opening the heart (see the photos opposite), one notices that the interventricular septum is composed of a rugged texture which lets some of the children think that there does exist "some of the holes" that let the blood pass through from one ventricle to another.



open left heart open right heart

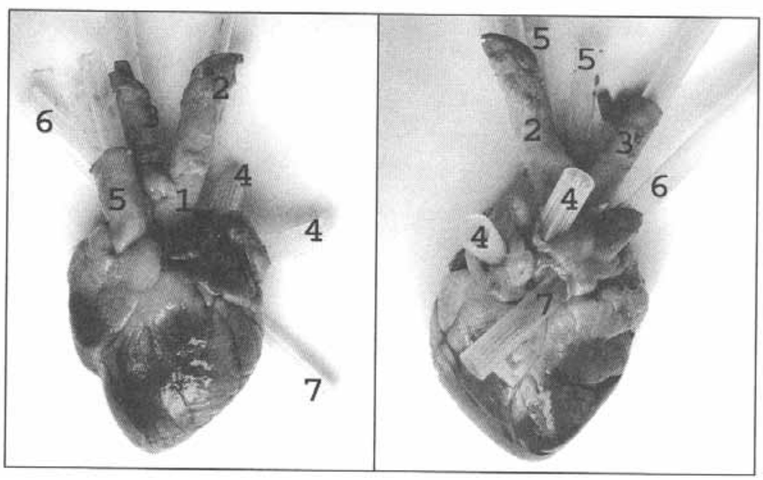
Photo Nadia Ouahioune *(End of inflated lung)*

To see if there is or not some “holes” in the septum, the children decided to fill the heart with coloured water (simply ink), of a predetermined volume, and to secure the two halves, using some elastic. For this the heart had to be separated from the lungs with segments of blood vessels, fairly long, (2 to 4 cm), as explained in the appendage. Also, the heart can remain “standing” in a transparent plastic glass. Some hours later, or at the end of the day, you carefully empty the heart keeping the liquid. First the right heart: the coloured water emptied out, the volume is measured and found to be exactly what was introduced. The same procedure was carried out with the left heart, but no liquid came out. The coloured water has not therefore passed to the left heart. The septum which separates the two hearts is therefore watertight, as Ibn al-Nafis thought.

How to test Ibn al-Nafis’s theory

For Ibn al-Nafis the blood’s journey between the heart and lungs is made on a one way system according to the following stages: arrival of the blood in the right heart -->leaves the right heart via the pulmonary artery -->the blood enters the lungs -->leaves the lungs-->the blood returns to the left heart via the pulmonary vein. Also, according to Ibn al-Nafis, the blood that passes from the right heart to the lungs via the pulmonary vein, is mixed with “the vital breath” and rejoins the left heart via the pulmonary artery.

The children proposed to inject the coloured water into the vessels, to simulate the blood and to see where the coloured water entered and exited. After several tries with different vessels, the children noted that the coloured water injected into the vena cava (at the right heart) exits via the pulmonary artery. If the injection is made by the pulmonary vein into the left heart, the water exits via the aorta artery.



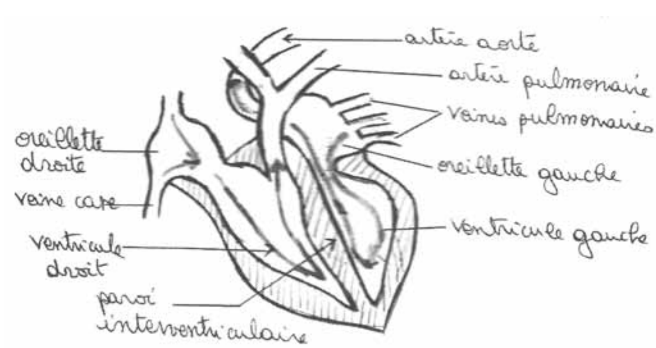
Sheep's heart

Anterior (front) view Posterior (rear) view

(photo Didier Pol, Multimedia)

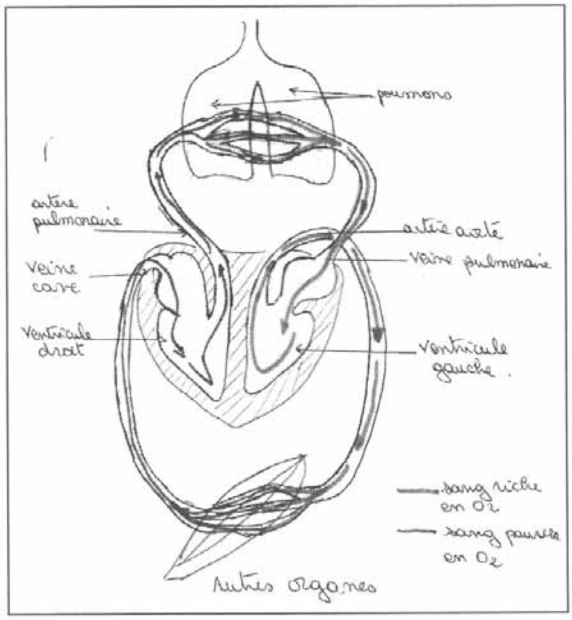
1: exit of aorta trunk ; 2: aorta; 3: right trunk cervicobrachial; 4: pulmonary vein; 5: pulmonary artery (pushed back to the right heart for the aorta egress); 6: vena cava major; 7: vena cava minor.

With the help of a diagram of a dissected heart, the children trace the blood's journey in the heart;



Epilogue

The story of the circulation of the blood does not stop with Ibn al-Nafis. With him we have determined the course of the blood, from the right heart to the lungs and from the lungs to the left heart. But we had to wait until Harvey to demonstrate that the blood leaves the heart and returns there in a circle, relying on the small or pulmonary circulation, to the large circulation.



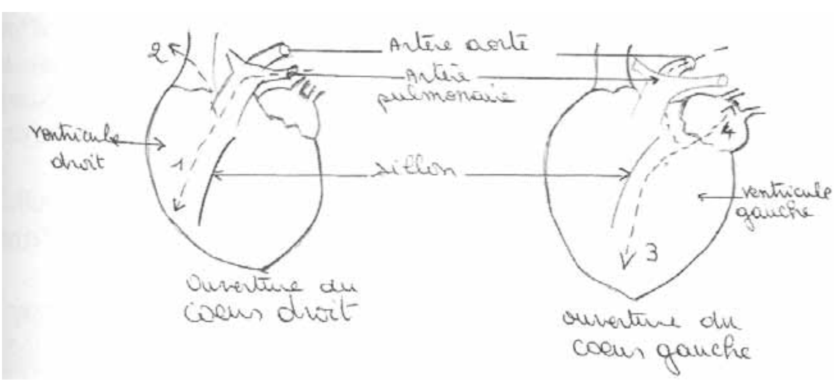
Appendage

Experimental procedure of dissection

Place the heart in a dissection dish so that the ventricle is facing you.

Opening of the right heart: Insert the scissors in the artery attached to right ventricle (pulmonary artery) and cut along the length above the interventricular wall (incision 1-2).

Opening of the left heart: Insert the scissors in the artery to the left ventricle (pulmonary artery) and cut along the length above the interventricular wall (incision 3-4).



To mark out ventral and dorsal faces of the heart

The ventral face, on the inverse of the dorsal face, presents an oblique interventricular wall and it is bulged out. With the straws inserted in the blood vessels, one notices that the heart comprises of cavities separated by a partition corresponding to the exterior interventricular wall.

To detach the heart from the lungs

It is necessary to section the heart vessels being careful to keep about 4 cm above the heart in order to help with the examination of the colour and texture of the partition. These segments of 4 cm can also ultimately be used to insert the plastic tubes and to be injected with the water (with syringes) and also to determine the course of the blood inside the heart. Lastly, the opening of the right heart and of the left heart is easier and the sigmoid valves are safeguarded. One can also obtain hearts from abattoirs, but often they are slashed and the vessels are sectioned too short.

Photograph of the children in CM1 Joliot-Curie school (Montreal)

To mark out the two types of blood vessels on the major part of the heart

The arteries: partition white and rigid,
The veins: partition red and smooth.

To go further

The presence of air in the lungs is understood by the children, as a fact that the air enters into contact with the blood in our lungs but it is quite another thing that it is a “mixture” of blood and air at the pulmonary alveoli stage. The teacher suggests eventually, an experiment to visualise this action of the air, or more exactly the deoxygenization of the blood.

Two containers containing blood will be used. In one, an aquarium aerator is placed and the blood shows a bright red colour, whilst the second is closed, shows a darker red colour.

The difference in colouration of the two containers gives you the opportunity to ask the question on the link between the air and the blood contained in the lungs: how does the blood arrive in the lungs? Where does it come from?

TThe favourite game of Nabil and his sister was to resolve problems which arose as they were observing what was going on around them, or in them. They were much more passionate about this than others of their time, a little magic was amongst them, as the day when they wondered why their heart beats were so strong inside their bodies when they were out of breath. . .

It all happened when they had escaped from one of their big sisters who they had teased. They reached unencumbered their place on the riverbank and they were very much out of breath. His arms on his hips, he interrupted his sister:

— Fadila, put your hands on your chest; can you feel something beating strongly?

— Yes, it's my heart that is beating strongly and I have difficulty breathing, I am breathing too quickly.

— Me as well, Fadila, we must wait awhile.

However he soon got his breath and said:

— Put your hands on your neck, it beats strongly there also.

— Yes, but I get the impression that it is calming down, and at the same time we are breathing less quickly!

— Yes it's calming down, it's calming down, but I am wondering what is beating in my fingers?

— Nabil, it is blood!

— Blood, really? How can you be sure? You cannot see what is happening inside the body whilst you are living, that's the problem!

A little disappointed that their query could not be quickly answered, Nabil and Fadila left to walk along the riverbank and the irrigation canals that watered their fields. Fadila stopped suddenly.

— Look Nabil! The water goes to join each little piece of earth through these grooves! And if the current becomes too strong it overflows! That makes me think that the blood which flows when we are injured. . .

— You have some bizarre ideas, Fadila! Here is the flowing water, and it comes from the river, whilst the blood, usually, stays in the body!

— But I know that, I am only trying to understand! And then, I think you want to know as well, what happens inside our bodies!

It was then that Nabil and Fadila heard a massive thunder-clap of laughter. They turned around and saw a man whose clothes and turban were an immaculate white, as was his beard.

— You have heard everything we have said and you mock us. Who are you?

— It is not you that I am mocking, it's the savants whose books I have read, and they did not have as good ideas as you! I am called Ibn al-Nafis, I directed a hospital to look after people, but I am also interested in the interior of the bodyof those who no longer exist

— Ibn al-Nafis, would you like, please, to help us to answer our questions?

— Yes, but not her, for it is excellent to reflect, but it is also necessary to observe. Follow me, and you will understand how blood travels by the heart and lungs to keep us alive!

What happened next has not come down to us, for it happened a long time ago, the memory is lost! It only remains that Ibn al-Nafis was the first to discover how the blood continuously renews itself in us from the air that we breathe. And in one way or another, just as he beforehand joined Nabil and Fadila, he will join all of us today and all those who ask the same questions. In one way or another. . .

The rainbow

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The theory of the rainbow

The sun has succeeded the rain, which is still falling over there, a little way away. The trees are shaking. In the rain clouds, a rainbow. It was there, faithful to the drops of water and light mixed, after the storm, in the fountains, under the oars of the boats. A circular arc. Opposite the sun. The red outside, the blue on the inside, yellow in the centre. Sometimes a second rainbow, above, less intense, its colours inverted: blue on the outside, red on the inside. The rainbows are high in the sky at dawn, sleeping: nearly a half circle on the horizon. An observation shows it: the centre of the rainbow is always opposite the sun in relation to the observer. Thousands of people look at it, thousands lie at its foot; one piece for each spectator. It is useless to dig to find its treasure. Red is always at the same angle right to the sun-eye-centre of the "meteor" as it has been called since Aristotle, because it unfolds in the air. The other colours are always at the same angle, constant.

The appearance of this natural phenomenon has given rise to numerous myths: the Arabs knew that the Greeks have made a copy of it as the goddess Iris, a messenger with winged feet, who carries Zeus' orders to the gods and the omens to men. They read in the Bible, that the rainbow appears to Noah at the end of the deluge, a sign of the alliance between God and man. The meteor intervenes in John's Apocalypse: it is he who sits with Christ on the Judgement Day. In all its interpretations, the rainbow often represents a dual principle: sun-water, earth-sky, god-man, and masculine-feminine.

It was Aristotle (IV century) who gave the first scientific explanation of this phenomenon. He distinguishes the explanation of colours, which come from the “physis” (physique, physiology, psychology), and in this form, which is a geometry problem. The colours: he considers (wrongly as will be determined 2000 years later) that white is pure, homogenous, whilst the colours are mixtures, of “reductions” in sight. The colours of the rainbow were the reflection of a cloud. A large scale mirror reflected the form and the colour (your figure and the colour of the skin). A piece of its feeble dimensions can only send colour (that of your skin, you can no longer see your complete opposite). As the meteor shows continuous colour and not a picture, this is due to their reflection on small mirrors. These mirrors are made up of small drops of water forming the cloud. The form: the eye emits visual rays. They reduce according to their distance. Each colour corresponds to a particular reduction of white. The same colour is painted at the same distance as the eye, therefore in a geometric line it is a circle. This has at its centre the opposite of the sun in relation to the eye, so that the cloud sends us the reflected rays. The importance of Aristotle’s philosophy will make the study of the conception of the rainbow to be carried out by all his successors, in the science of Islamic countries in particular.

One of Aristotle’s commentaros, Alexander of Aphrodisa, circa 200 AD, remarked and described a phenomenon that no-one had previously emphasised: the band of sky between two rainbows is always dark. Why should this be this relative obscurity “Alexander’s band”, as it has been known as ever since. Science developed in Islamic countries is going to reply to this question and to fundamentally re-examine the explanation given by Aristotle.

The greatest of Arab physicians is, without contest, Ibn al-Haytham (Alhazen) (965-1041). He was the first one to interest himself in the physical nature of light (see “the light ray”), that he thought is composed of small similar spherical particles. He justifies this hypothesis and explains all the light facts that he knew by experimentation. He also studied the “burning spheres”, glass spheres which concentrate the light rays and can start fire, the base of a glass, a magnifying glass. . . Thanks to a precise experiment carried out in a darkened room, you can trace the rays coming in, they are refracted (by coming through the glass), coming out of these spheres (see figure 1). They therefore demonstrate (see figure 20) that the parallel rays coming from the sun and which fall on a sphere make different angle indices, that they are refracted and come out of the air always according to angles between 0º and a limited value (according to the arc O'G of figure 2): no ray can leave to the exterior of G. We will see the importance of this conclusion. Ibn al-Haytham added little to Aristotle's conclusions regarding rainbows, He replaced and it is important "the visual ray" by "the light ray" coming from the sun but gave no other explanation from his experimental method or conclusions that he obtained from optics. At the time when he lived Ibn al-Haytham, Ibn Sinâ (Avicenna) had had the idea to no longer explain the rainbow by its reflection on small mirrors situated in the clouds, as Aristotle, but by the reflection of rain droplets. This important idea did not hold, in the actual state of our knowledge, to be taken before the works of Kamâl al-Dîn al-Fârîsî ash-Shirâzî (died 1311), Astronomer at the Maragha observatory who taught him optics at Tabriz and took him from Cairo, to comment on the original experiment of Ibn al-Haytham's *Book of Optics* written by the author's hand.

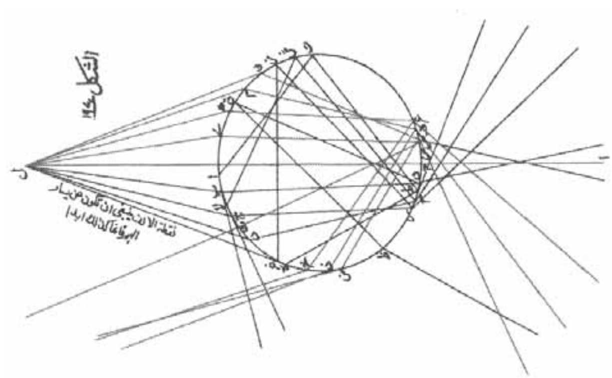


Figure 1 : Lines of light in a glass sphere according to Ibn al-Haytham

To modify the idea of the rainbow, al-Fârisî certainly relies on revising the work on optics by Ibn al-Haytham, on the ideas of Ibn Sinâ (the light reflects off the raindrops and not the drops formed in a cloud) and on the ideas of d'ash Shirâzî (the light refracts in raindrops then is reflected on the their rear face, but he didn't demonstrate this proposition and confided this information to his pupil). Being concerned with the geometry of the meteor, al-Fârisî retook the diagram of the lines of the light rays in the ardent sphere as was realised by Ibn al-Haytham and identified each raindrop as such a sphere. But whilst his illustrious predecessor was interesting himself with all the light rays that could come out of the sphere, al-Fârisî only occupied himself with the rays that could come out in the direction of the eye of an observer placed between the sun and the rain. He also demonstrated that the rays entering the droplet, reflected themselves on the rear face and left again by the front could converge on the spectator's eye (see figure 3 following). Al-Fârisî was a little mistaken with the value of the angles: here he does not experiment himself but retakes the determined values by Ibn al-Haytham thanks to the ardent glass sphere, whilst he would have had to take the determined values on the spheres filled with water (different refraction index).

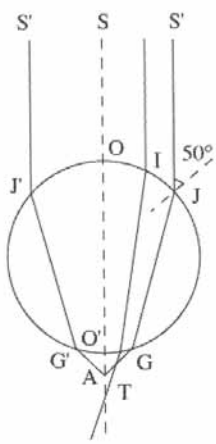


Figure 2 a

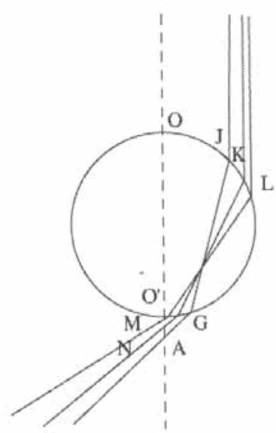


Figure 2 b

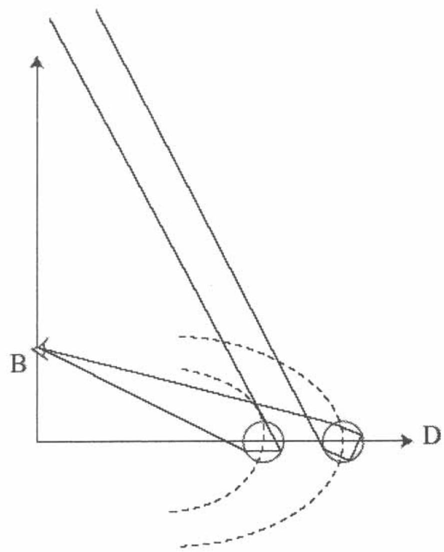


Figure 3

To explain the colours, al-Fârisî observed the iridescence that was present in rose droplets or the water contained in a receptacle placed in the sun. From the evidence, these colours are not due to different distances, to “fading” of the view as Aristotle supposed, but to the phenomenon of refraction. Returning then to the geometric notes of Ibn al-Haytham, he noticed that incidents of parallel rays gave refracted cones that could cross and reinforce more or less at the same point (cones such as JG, J’G’, GTG’, LM, J’G’, LM, of figure 2) For him, there were four colours in the rainbow: blue, green, yellow and red. Blue was due to the rapprochement without stacking of cones green has partial cone stacking, green has complete stacking, red appears on the border of the cluster, more light. . .

Why should the colours of two rainbows be inversed and those of the second darker? Al-Fârisî remarks that a reflection inverts the image. The first rainbow is associated with a reflection to the rear of the raindrops, the second with two reflections: the colours of one are therefore inverted in relation to each other. A reflection loses some light: the higher rainbow is therefore less intense. And what about Alexander’s band? Ibn al-Haytham has demonstrated (see figure 2) that no ray can leave by the exterior of OG’. This is the limit from red, the exterior of the first arc, the interior of the second: between the two, there is no light transmitted by the raindrops, the sky is darker. Why is the rainbow sometimes incomplete? It marks the intersection between the area where it is raining and that which is clear by the sun’s rays. Why do we see the colours continuously whilst the raindrops are not continuous? They are very numerous and, from afar, we cannot distinguish the discontinuities, moving.

The rainbow experiment is complete in the general sense that is known by the world, in general agreement with the vision of Aristotle, but considerably enriched by the introduction of a new physical object – the light – and the adoption of experimental ways. To suggest it, al-Fârisî has just interpreted his experiments not carried out on the raindrops, impossible to isolate to study, but on a glass sphere filled with water. Ibn al-Haytham has had recourse from his diagrams which have enabled him to keep a technical check on the geometric propositions (geometry and optics of Euclid considered their properties and their courses, Ibn al-Haytham substituted them with rectilinear light rays, which reflect and refract); he had assimilated the reflection and refraction of the light by the behaviour of hard spheres launched at great speed and he then calculated the movement by mathematics.

These innovations, promises for a good future, did not come to pass, in the actual state of our knowledge, to develop in Islamic countries: in the era when al-Fârisî the traditional meeting rounds of scientific exchanges became disorganised: The Ottoman Empire was founded in 1291, the circulation of writings did not produce anything further between the Eastern and Western Muslims, and they themselves went into decline. The Latin countries were getting better at science from the end of the XI century compared to the Islamic countries. Their translators had put forward the works of Ibn al-Haytham – apart from the introduction explicitly stating the experimental method. Thanks to the writings of this master, the explanations of the rainbow were starting to be developed in Christianity with Roger Bacon 1267, Witelo 1278, Dietrich de Freiberg. Who were also to make conclusions around the same time as al-Fârisî, as to the full explanation of the rainbow, but with less precision and following a marked mystical approach, very different from the more scientific approach in Islamic countries, which have always been detached.

The philosophy of the Middle Ages also fell into decline. The explanations of al-Fârisî and Dietrich de Freiberg will be forgotten with the

the constitution of “modern science”, of the patrons’ of the XVII century, Ibn al-Haytham remains, however, well known and present in the books of savants of this era. It was René Descartes who, in his *Discourse of the Method,* then *The Meteors,* then *Geometry* which are the application of this method 1647, will re-find, thanks to the law of refraction by Snell, who was the first to publish, the complete geometrical explanation of the rainbow, surpassing in precision that of al-Fârisî. It was Isaac Newton 1672 who completely quantified the rainbow and its colours, making from the white a heterogeneous mixture and distinguishing seven fundamental colours, as there are seven notes in music and seven planets [sic] . . . The figure 7 represents for him the coherence and the Creation. In the XVIII century, some other characteristics of the rainbow were observed: some coloured fringes can appear in the interior of the first arc and on the exterior of the second, the meteor emits polarised light. . . Not explained by Newtonian physics, they lead to other developments. . . But this is another story, which can be developed because, here as elsewhere, science in Islamic countries had founded the pedestal on which our science has evolved.

For extra information

Bernard Maitte, History of the rainbow, Paris, Seuil, coll. “Open Science”, 2005

The light and the water: the discovery of the rainbow with al-Fârisî

Objectives:

White light is composed of infinity of colours.

Raindrops decompose the white light. To observe a rainbow, an observer should have his back to the sun and face the rain.

The coloured lights are not composed of pigments of colour (like paint).

Reference to program:

"The sky and the earth : light and shade".

Equipment used:

A glass with a stand full of water, torches, spots of colour (red, green, and blue).

The approach that we are going to undertake here, is empiric, based on observation and experimentation. We will see, for example, that a rainbow is only visible in certain observational conditions and that there are certain common points between each rainbow, invariants. Following on from al-Fârisî, the pupils will be encouraged to explore the conditions in which rainbows can be observed. They also discovered the respective positions of the source of the light and the water in relation to themselves. They even noticed that the outside colours of the rainbow were always the same. This sequence will also be the opportunity to break with certain ideas held by the children: the rainbow is not a material object, there is no advantage in having the seven colours. These discovery activities lead us, lastly, to investigate some physical aspects of the colours.

For the master

Colour is a subjective sense which results from a cerebral interpretation of the light by the retina of the eye. It therefore does not exist from a colour "itself"; it is a response of the brain to a stirring of the eye's photoreceptive cells (the cones situated in the retina) by the light. This stirring gives birth to a nervous signal transmitted to the brain by the optic nerve. To understand the colour, we have to go back to the physiological mechanism of sight. This approach is going to let us complete what was presented in the part about the physical interpretation of sight by Ibn al-Haytham.

Let us consider light as a wave. A certain type of wave, a particular one, but a wave nevertheless. It is characterised by the length of the wave, which is measured in nanometres (1 nm = 0.000 000 001m) or, what returns to the same, by frequency, measured in hertz. Our eye (or more exactly, its photosensitive cells) is sensitive to electromagnetic waves, whose frequencies are between $7.5°10^{14}$ and $4°10^{14}$ Hz. In other words, the photoreceptive cells send a signal to the brain as soon as they are reached by the electromagnetic waves the length of the wave varies between 400 and 750nm. You call all of these waves, this light, the "visible light", in the sense that provokes sight (don't forget that light is invisible!) The cerebral interpretation in terms of "colour" of the light received depends on the length of the wave (or the scale of the wave's length) received. Also, the length of each wave received is associated with a colour. For example, the colour violet is a sensation of the eye's photoreceptive cells by a light whose wave length is between 400 and 450nm. When the eye receives a light of a single wavelength, you are talking of "monochromatic light", but this is almost never the case. . .

The spectrum of white light is cut away in a simplified manner in *three bands* corresponding to the colours red, green and blue called the *fundamental* colours.

Man has the ability to distinguish between a great number of colours (nearly a million). However, the retina does not possess as many types of photo-receivers as there are colours identifiable by man. In fact, there are three types of cones which we will call b, v and r respectively [*b, g, and r*] sensitive to wavelengths are:
— between 400 and 500 nm;
— between 500 and 550 nm;
— between 550 and 750 nm.

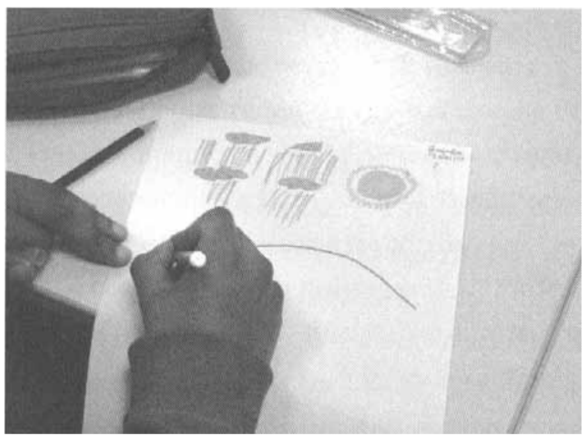
The proportion of excited cones and the stacking of the signals coming from different cones allow, by additional synthesis, the sight of all colours.

It is not necessary to go through all this with primary school children. But this theoretic point allows you to make, without doubt, particular attention to the idea largely agreed upon, about which colour and material colour are one and the same. Also, the material character that the pupils spontaneously attribute to the colour is it opposite the abstract character of the sensation of the colour produced by the light. This said, let us enter the fascinating universe of lights and coloured objects.

Activity No. 1: The pupils' ideas about the rainbow

Here we will try to characterise the way in which the pupils understand and explain spontaneously the formation of a rainbow. This stage is going to guide the classes to come to the instructions suggested by the master, "Represent a rainbow in a way so that an other person can understand how it is formed", is written on the board. The children reply individually.

The examination of the children's ideas raises several questions in relation to the colours (how many are there? In what order are they found? Is this order always the same?), for the chronology of the events (is it necessary that the sun and rain are present at the same time or do you have to wait for it to rain before the rainbow appears), to the respective positions of the elements necessary for the rainbow's formation. These questions are examined in a debate organised by the master. For each theme (colours in the rainbow, chronology of events, position of the sun, of the rain), the master shows some contradictory drawings on the table and asks the pupils to discuss their pertinence (see photograph below). The children think only of counting the sun's and rain's presence. They accord no importance to the position of the sun in the sky. However, they debate in a lively fashion about the position of the rain in relation to the rainbow: is it "inside", "behind"? Concerning the general mechanism of the formation of the rainbow, the pupils are heard to say that "it is the light of the sun that comes to be placed in the water, and this forms the colours". We notice that the observer is never spontaneously drawn by the pupils.



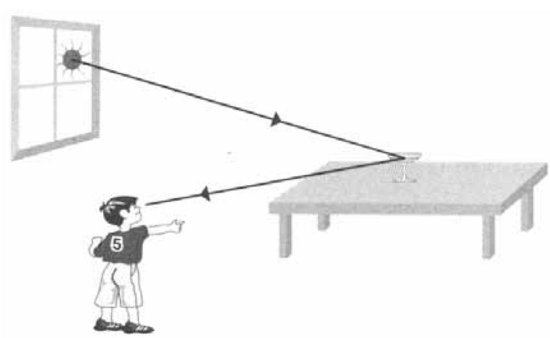
Drawing by year 3 pupils (CM2) in response to the instruction: "Draw a rainbow. So that another person can understand how it is formed". Some of the drawings present the events as they occur in the time. This provides the means for a discussion: half the pupils of the class affirm that the presence of the rain and the sun should be simulated, as the drawing illustrates.

The intervention of the master and the reading of the text allow the children to respond to certain questions, notably to those concerning the number of colours: there are not seven colours in the rainbow (generally you can only distinguish four or five). By the end of the class, there are still some questions which are an echo of those posed by Nabil and Fadila in the children's text. They are written on a notice and define the organisation of the following classifications:

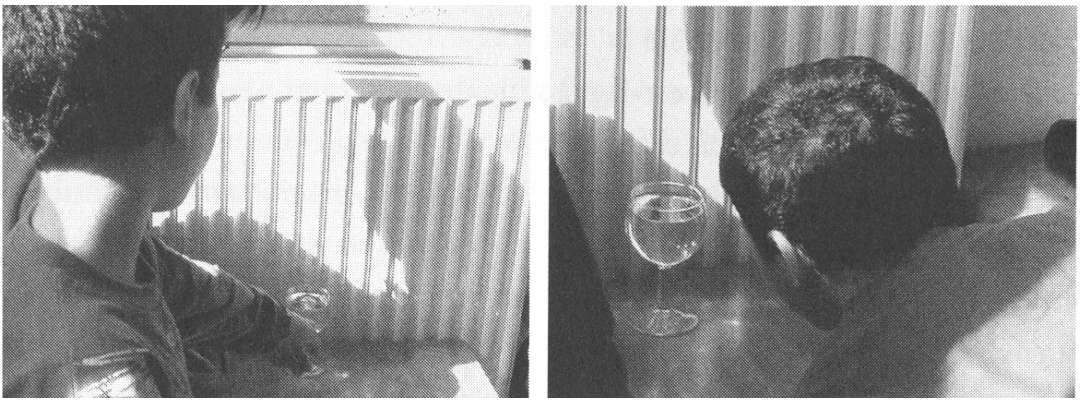
1. What are the colours as defined by the rainbow? Are they always arranged in the same way?
2. In what conditions can we see a rainbow? Can we make a rainbow in the classroom?
3. Can you touch a rainbow? Is a rainbow a material object?
4. Which hypothesis have the savants formulated to explain the formation of a rainbow throughout history? What could the savant al-Fârisî have said to Nabil and Fadila before the secret was lost in the sands of time?

Activity No. 2 : Making a rainbow in the classroom

In order to reply to the first three questions listed above, it is necessary for the pupils to make a rainbow. Now, this phenomenon, being fairly rare in nature, the teacher invites the pupils to think of a means to make the rainbow in the classroom. The pupils have no doubt that water (in particular, the rain) is necessary for the formation of a rainbow. Sun is also necessary. Some of them suggest using a hose pipe in the playground in the sunlight. This experiment is done in good weather. Others propose to pass light through water in a container. The pupils are put into groups of four and given a glass with a stand on full of water and a torch. The classroom is darkened and each group attempts to produce the colours of the rainbow. After a few minutes research, they note that it is possible to observe a very small rainbow inside the glass.



This is not visible by every member of the group, only by those who found themselves behind the light. The experiment is then conducted with the sunlight coming in through the windows.



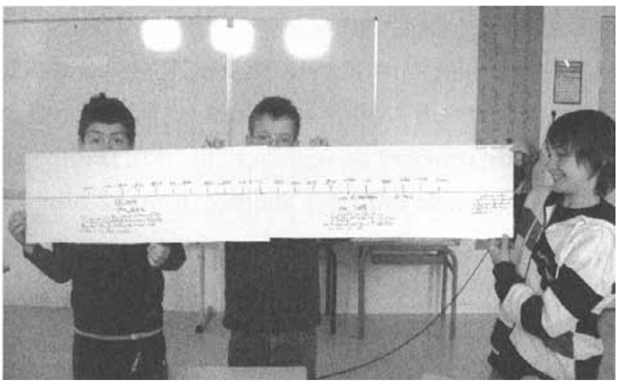
A rainbow is visible thanks to the sunlight, on condition, once again, that the sun is behind them.

The pupils note that the order of the colours is always the same, (from violet to red), that the reaction of the sun and water is simultaneous, that the rainbow is not an object that you can handle, and, above all, that its appearance depends on the position of the observer in relation to the water and the light source. The fourth question remains, however, how can you come to understand the formation of a rainbow?

Activity No. 3 : Historic approach

The phenomenon of the rainbow has been subscribed to by many interpretations over the course of the years. The animation "The rainbow theory of al-Fârisî" presented on the website www.lamap.fr/decouvertes remembering that some of them will be suitable for discussion with the pupils. Having put aside the space and time (with the help of documents as distributed by the master or on the Internet) the different savants that the animation mentions (Aristotle, Ibn Sinâ, Ibn al-Haytham and al-Fârisî), you ask them to associate each experiment or conceptual advance with the author (see table below).

Savant nominated	His explanation of the rainbow phenomenon
Aristotle	Small mirrors are present in the clouds resending the sunlight. This resent light is impure and forms several colours.
Ibn Sinâ	Rain is necessary for the formation of a rainbow
Ibn al-Haytham	Spheres filled with water become sunlight
Al-Fârisî	A rainbow is only visible when a light-beam comes from the sun and penetrates a raindrop showing into the eye of the observer. For this, the observer must face the rain with his back to the sun.



This work document, together with the animation, is a chronological freeze: "The contribution of Arabic savants for the explanation of the rainbow"

Photograph – the explanations suggested by Aristotle, Ibn Sinâ, Ibn al-Haytham and al-Fârisî were placed on a chronological freeze made by the pupils after seeing the animation and doing the documentary exercise which accompanies it.

But certain questions remain, notably that of the presence of colours. At this stage, the raindrops have a mysterious power, coming out of black boxes, capable of revealing a palette of infinite colours that the sunlight is composed of. It was necessary to wait until the XVII century and the works of Isaac Newton to understand their origin. Even if the question of the rainbow's origin of colours is not fully dealt with here, it certainly appears possible to envisage some activities to familiarise the pupils' with some ideas relative to the physiology of the white light and the sight of coloured lights. This done, we lead the pupils to distinguish the behaviour of the coloured material (and especially the mixture of pigments that are familiar to them) and that of the coloured light.

Activity n^{o}. 4 : Adding the coloured lights

1. To produce and to see the colours with the mixtures of coloured lights

The proposed situations now, have for their goal to create a conflict between what the pupils are expecting to see and what they actually see. This is designed to give them a new approach to colour, different to that which they have acquired in visual art for example, when they have mixed certain paints to obtain new ones.

Each group of pupils have three light sources of different colours at their disposal: one source red, one green and one blue. You ask them to make different colours out of the light sources. Their replies were strongly influenced by the confusion about the mixture of paints and the mixture of coloured light. Some of the pupils foresee, for example, that you can obtain "chestnut from mixing green and red, or mixing the three lights". Every time, the experimentation leads them to disassociate the two phenomenons. The mixture which is most surprising is the mixture of the red and green beams, which produces yellow (and not chestnut, as it does with paints). Adding green light + blue light = cyan, and red light + blue light = magenta. As to the three together red, green, blue beams, this produces a white light.

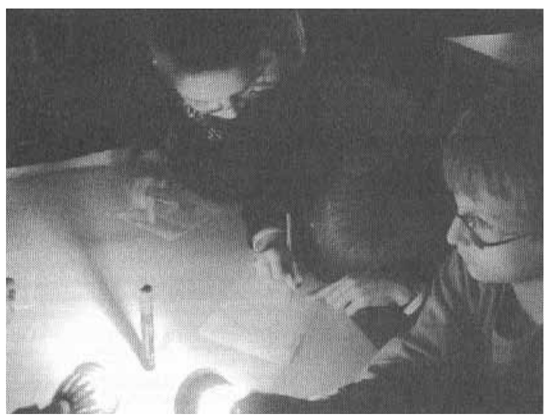
2. Making coloured shadows

For the majority of the pupils, a shadow is black, or grey. This last activity should make them understand that a shadow is not made out of black material and that it does not behave like a dark mark. In fact, a shade is an area of less intense light, it therefore sends less light back to the eye. If it is lit up by another light source other than the one that created it, it is going to receive (and therefore resend) a part of the light from this other source. And if this second source is coloured, then the shadow is going to be coloured too. To understand the formation of the coloured shadows is only possible if one has completely understood that a shadow is not tenable!

Stage 1 : Start by asking the pupils to guess what will happen if they light up objects with a red light (e.g. a pen). The pen is stood up on a piece of white paper. The pupils observe the shadow of the pen on the table. This appears as dark grey. It is surrounded by red light.

Stage 2 : What happens now if you light the same pen, at the same time with a red light and a green light (the two light sources are placed side by side)? What will you see on the piece of paper? Why? Most of the pupils guess that they will see two shadows surrounded by a yellow light, as the result of the green and red lights. But none of them guessed that the obtained shadows could be coloured, as it is the case: the preceding shadow is lit in green light and thus sends back this green light to the observers' eyes that see . . . a green shadow. Also, the pen intercepts a part of the green light. It forms a second area of shadow lit this time with a red light. The pupils observe therefore two pen shadows, each one of a distinct colour, one red, the other green, around these areas, the colours mix. Red light + green light = yellow light.

Stage 3: What happens if one lights the pen with a blue source and a red source? Then with three sources: blue, red and green? This stage seems difficult for pupils of year three. In fact, each of the formed shadows by the three light sources is lit by two sources. It sends back therefore a mixture of two coloured lights to the observers' eyes. One expects to see on the screen three circular areas of magenta, yellow and cyan, surrounded by a mixture of green, blue and red lights, or the white light!



The overall interpretation of the rainbow appears difficult to for primary school or college pupils. However, the opening for the Arab savants of the X century A.D. starts in the classroom, the comprehension of the marvellous phenomenon that continues to fascinate most of the children.

The favourite game of Nabil and Fadila was to resolve questions which were suggested to them when they observed what happened around them, or inside them. They were more passionate about this than others of their time; a little magic was there, just as the day when an immense arch in flamboyant colours rose up in front of them in the sky. . .

That day, Nabil and Fadila were chatting as they trotted along the field, not seeing that the sky was changing into big dark clouds. Suddenly surprised by the rain, they ran for shelter under a big Sycamore tree. They were against the tree trunk under cover of the leaves, they were dry. However, Fadila grumbled about her damp clothes. Her brother interrupted her :

— Stop grousing, Fadila, the sun will soon return!
—You know that! Look, it always rains. . .

Nabil took three steps to the side and took a furtive glance behind him. He threw a malicious smile at his sister:
— Right in front of us, yes! But go around the trunk and look behind us; what do you see?

Fadila went around the tree trunk and then her expression lit up suddenly;
— Oh, the sun is coming back! How can it rain and. . .
She was interrupted by the great shout that Nabil made;
— Come back to the side Fadila, look!

In the sky there was still rain, a great coloured arc illuminated the sky. Fadila stayed silent in surprise at this prodigy, Nabil joyfully said:

— Look, all the colours are suspended in the sky!

Fadila had regained her composure and added attentively:
— No, me, I cannot see all the colours, just four: red on top, then yellow, green and blue at the bottom. . .
— Fadila looked again, can you see between the red and yellow there are other colours, and others still between the yellow and the green, and also between the green and the blue. I bet you there are at least . . . a dozen colours!

Fadila, could sense them better because the sun was warming his back, became suddenly animated. She asked so many questions all at the same time that Nabil could not answer them:
— Who could say which one of us is right? And then, how were these colours suspended in the sky? And then, how are they always in the same order? Is it necessary for it to rain and to have sunshine at the same time? Nabil, do you believe that one day we could know the answers?

Nabil had fixed his gaze on the sky. He made a sudden sign to his sister to be quiet. Fadila raised her eyes and saw a man with a long coat the colour of the sky and a turban of the colour of the clouds who had appeared under the coloured arch. It seemed that he too was suspended in the air, but he addressed Nabil and Fadila distinctly:
— Hello, I am called Kamâl al-Dîn al-Fârisî, It appears to me that I have arrived at an opportune moment! Do you know that numerous savants have worked on the colours of the rainbow and that thanks to their efforts and their experiences, their secret has been divulged? Would you be interested in knowing them?

In front of their shining eyes Nabil and Fadila, silently smiled. He took some round vases from his coat which he lifted to the sky to fill them with rain water and picked a spot in the shade near the sycamore.

What then happened on that day is no longer known, it was a long time ago, the memory is lost in the sands of time! It only remains that Kamâl al-Dîn al-Fârisî had succeeded in being the first person to make the theory of the rainbow. And in one way or another, as he had accompanied Nabil and Fadila long ago, hetags along all of us today who ask the same questions. In one way or another . . .

The astrolabe

[an early form of sextant]

From al-Khwârizmî to al-Zarqàlî 68
The astrolabe became the king of instruments
Philippe Dutarte

The astrolabe or the heavens in your hand 83
Hélène Merle

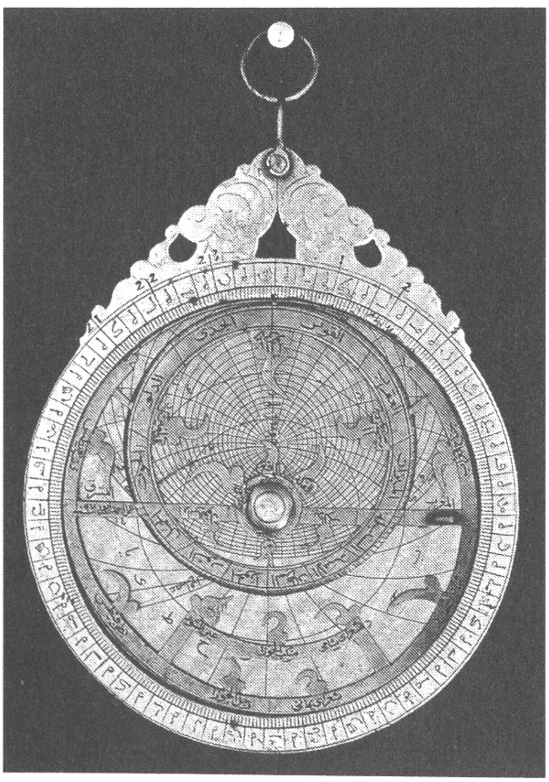
Children’s text 101
Anne Fauche

This chapter is recommended for college classes only. The historic and pedagogic histories presented are however useful to teachers to make up a sequence for astronomy adapted for their pupils and for primary school programmes.

From al-Khwârizmî to al-Zarqâlî
the astrolabe became the king of instruments

The astrolabes produced in Islamic countries, from India to Andalusia, from the VIII century to the beginning of the XX century were the kings of the goldsmith's work, that until today, sitting in the museums, exert real fascination. Beyond the mysterious beauty of the instrument, it is a veritable treasure of science and culture and it's a historical voyage of the sciences and the people that give us the astrolabe.

Born out of geometric Greek representation of the sky of the II century A.D.[1], the astrolabe simulates, by projection, the movement of the stars and the sun, such as we know them. It lets us measure the time and to resolve certain astrological problems, but in astrology too, the influence of the stars is being generally taken into account, in spite of the disapproval of theologians and philosophers.



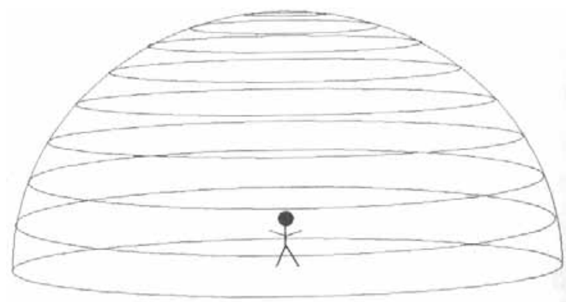
The astrolabe of Mahmud ibn Shawqa al-Baghdadi, made in Baghdad in 1306-1307 (Institute of the Arab world, Paris, inv. No. AI 86-14)

According to the specialist history of astronomical instruments David King[2], referring to information of the Arab bibliographer from the X century Ibn an-Nadîm, the first Arab astronomer who made an astrolabe was Muhammad al-Fazari, who lived in Baghdad in the second half of the VIII century. From its introduction into the Islamic world the astrolabe found itself in lands particularly propitious for its development, for political and religious reasons of the era. The Muslim religion made, without doubt, in this area of the world the only one at the time to have a need so pronounced for measuring time and space, having recourse to astronomy for the hours of prayers, the orientation towards Mecca or the fixing of the calendar. Besides the caliphs financed the researches, the construction of the instruments and observatories that allowed the best way of registering the vast spaces of their empire and to decrypt the celestial messages. The infatuation of men of power with astrology benefited science. It is within this sphere that in the IX century, the great savant al-Khwârizmî, founder of algebra as a new discipline, made three essential innovations to the astrolabe: the azimuthh lines, for direction, the "square of shadows", to measure inaccessible distances, and the sinus quadrant, to make the calculations in trigonometry. One can say that the astrolabe became the king of mathematical instruments, with multiple functions, from the measuring of time added with the measuring of areas, easing mapmaking, topographical measurements and mechanical calculation of astronomical co-ordinates or trigonometry functions. More than a measuring instrument, the astrolabe is an instrument for calculation.

However, the astrolabe was not completely "universal". Its marks depended on the latitude of the place (the angle made to the centre of the Earth the observation place being the equator, to the north or the south), it is necessary, for large distances north-south, to change one of the pieces before using it. Research into a universal astrolabe, which could be used for all latitudes took its source as the "horizon tables" which appeared in the Middle East in the IX and X centuries and abutted the XI century with its invention at Toledo, in Andalusia, in two forms, by Ibn Khalaf and al-Zarqâlî (Azarquiel for the Latins of the Middle Ages). In all cases, the universal astrolabe did not eclipse the classic planispheric astrolabe. If it has been adapted to resolve certain questions, such as changes to the coordinates, it corresponds less well to the observer's vision of the sky and does not cover the same uses. We will come back to this.

If the astrolabe has accomplished its career as a scientific instrument, it has had several centuries of use, its open study, we will see, an actual gateway to the history of sciences and the practice of astronomical and geographic principles.

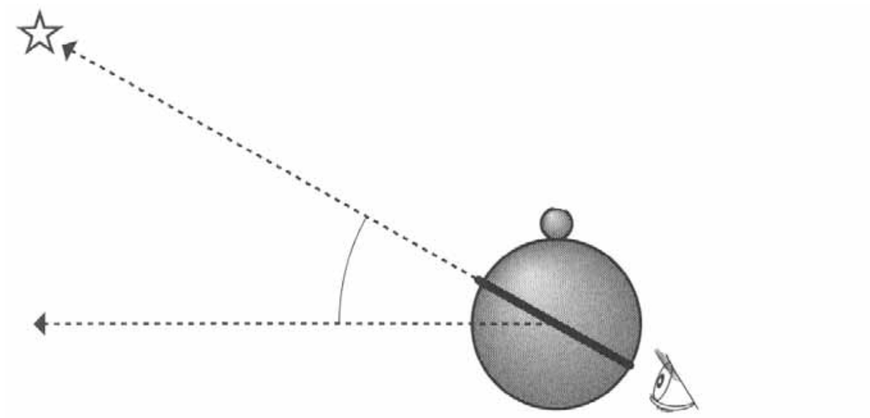
Taking the stars



Circles of height, from the horizon to the zenith, represented on a local sphere.

"Astrolabe" is a word of Greek origin, which translates, literally, "taker of the stars"; in Greek, *astron* signifies "star" and *labe* which is a derivative of the verb *lambanein*, which means "to take". What astrolabe takes to the stars, is the angle of height, or the altitude, that it has in relation to the horizon in relation to the observer. The angle of height is one of the two local coordinates (the other is the angle of azimuth), which allows us to pick out the stars in the sky: from 0º height, corresponding to the level of the horizon (in full visibility in the best case), up to 90º high, corresponding to the vertical of the observer, over the head (called the "zenith"). Imagine a large semi-sphere centred on the observer, the "local sphere", as in the figure above, you can figure out the height circles, for example every six degrees.

To measure the height of a star, you use the back of the astrolabe which you hold vertically. A vision regulator, the alidade (called *dioptron*, "dioptre" in Greek), slides on the graded protractor from 0 to 90º. To "take a star", you hold the astrolabe vertically by its suspension ring and turn the alidade to aim at the star across the two pinnules (small holes for sighting), to see the following figure. You then read the angle of height with the graded protractor on the side of the astrolabe.



Measuring the height of a star with an astrolabe.

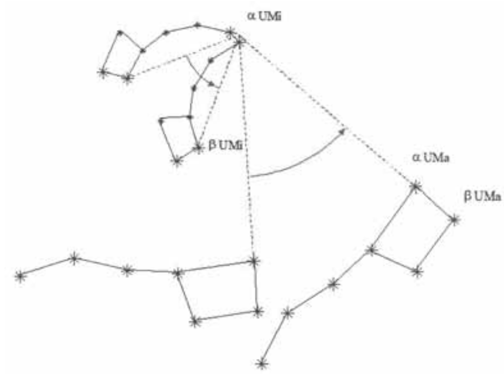
To take the sun, the procedure is a little different, because you cannot aim directly at the sun for fear of burning your eyes. You have to “”weigh”, as is the expression of the Portuguese navigators, whilst turning the alidade to pass the light beams across the holes of the pinnules in a manner that stacks the two round lights formed by the sun.

Once the angle of height has been measured, it is necessary to mark it on the astronomic face of the astrolabe, to place the sky in the apparent position that it is in at the time of the observation. The geometric representation of the sky and its apparent movements, which figure on the face of the astrolabe, allow us to measure the angle that is made. The star, that we want to know about, whose height we are about to measure, should be figured on the astronomic face of the instrument.

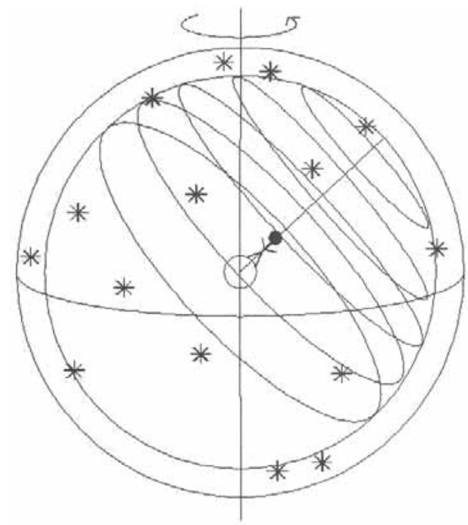
The gem of Greek geometry.

In the course of time, for an observer at a fixed point on Earth, the stars appear to turn around a celestial pole (point of the sky situated vertically from a terrestrial pole and in the rotating axis of the Earth). There is also the night, where you can also see the constellations turning around the pole, but also the day, when the sun seems to move.

You can, as did the Greeks, map the stars on a sphere, the “celestial sphere”, centred on the centre of the Earth and turning around it. In this model, the movement of the stars and the sun is therefore simulated with the help of two spheres, the fixed local sphere,



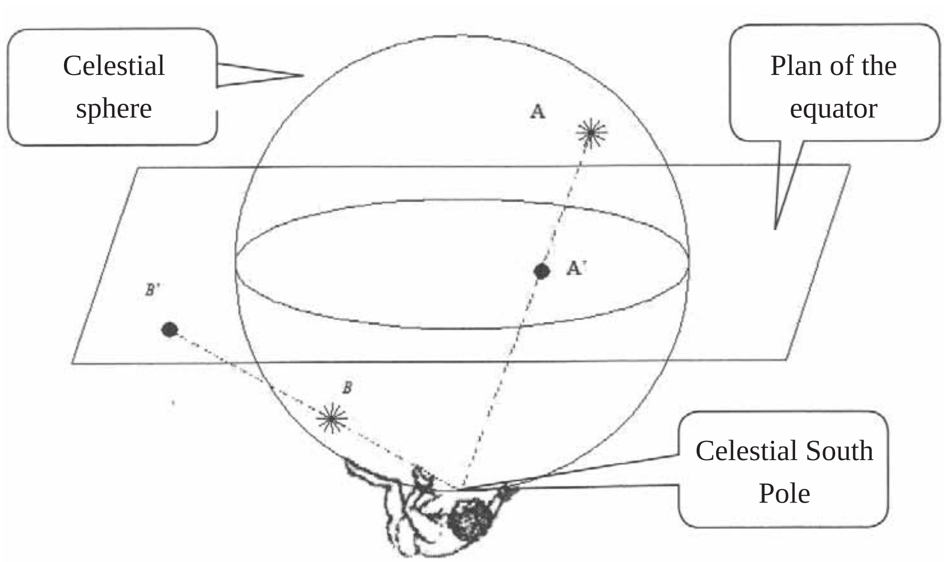
Local sphere fixed and celestial sphere rotating


Local sphere fixed and celestial sphere rotating

where the height circles are figured, and the celestial sphere, rotating on its polar axis, where the stars and the sun are figured. See diagram.

You do not have to believe that the sight of the spheres has a perimeter. You know for certain that it does not correspond to reality (the stars are not the same distance from Earth, situated on a rotating sphere), but it is always very useful for spotting the stars and the definition of their coordinates. The astronomical face of the astrolabe corresponds to a projection of the two spheres. The instrument allows us, therefore, "on the flat", to simulate the apparent movement of the stars. It is much more practical for travelling, rather than be encumbered with fragile spheres, and cheaper to make.

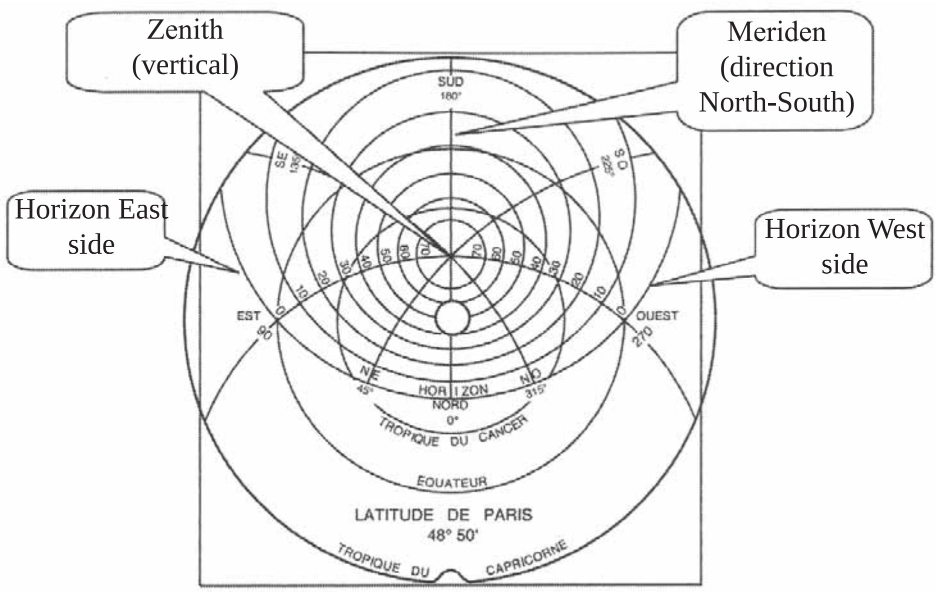
The "flat" principle of the spheres is that of a stereographic projection. Less barbaric than it first appears, it comes from a fairly simple visual projection. Imagine your eye being on the southern celestial pole (see the diagram) and look from this spot at the stars situated at the points A and B of the celestial sphere. The projections A' and B' of the stars are situated at the points where the visual beams meet the plan of the celestial equator. You can see that the nearer a star is to the South Pole, the further its projection is from the centre of the equator. You cannot project a sphere without damage and the planispheric astrolabe cannot entirely figure the sky.



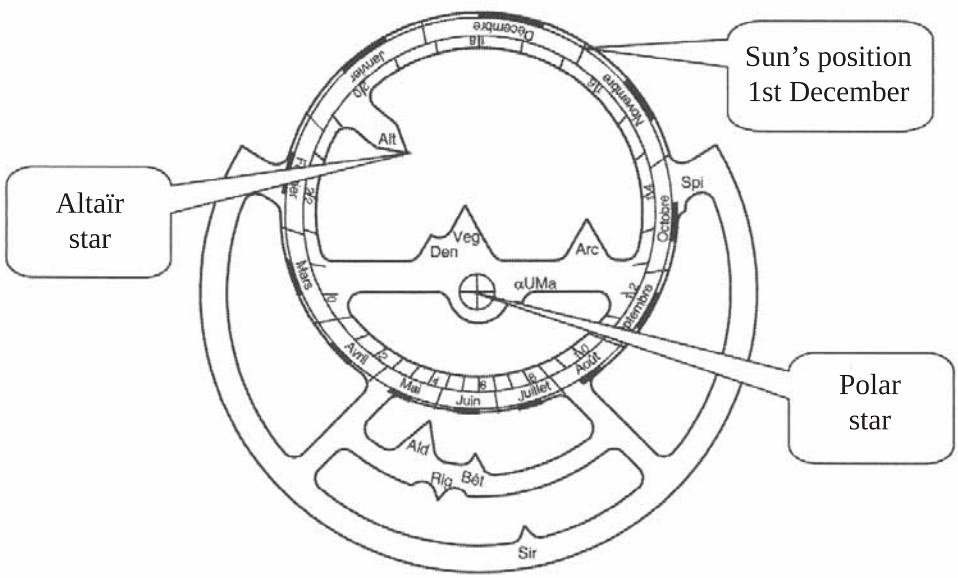
Stereographic projection of the South Pole on the plan of the equator

One of the important properties of this projection is to represent the circles of the sphere by the circles on the plan (or the laws that come from the circles passing through the South Pole). This mathematical property greatly facilitates the construction of the astrolabe for it is simple to trace a circle. The principle of the stereographic projection is due to Hipparque, about 150 years before this era; the instrument itself has perhaps been described for the first time by Théon of Alexandria (about 375).

The projection of the two spheres gives rise to the two pieces that constitute the astronomic face of the astrolabe. The local sphere gives the tympanum (see the diagram on page 74 top), traced for a latitude of observation, which is fixed. Figuring particularly on the tympanum the horizon circle and the height arcs (altitude), up to its zenith. The celestial sphere gives the "spider" (see figure page 74 lower), so called because of its open-worked tiled shape, the celestial map rotating around the celestial North Pole (a little thing near, the centre of the spider corresponds to the Polar star). The stars are fixed in relation to one another. It is this map of the stars that the points refer to. The sun is in an annual movement apparent in its relation to the stars. Its position is indicated on the spider by the calendar date.



Tympanum of the astrolabe for the latitude of Paris (48º50')

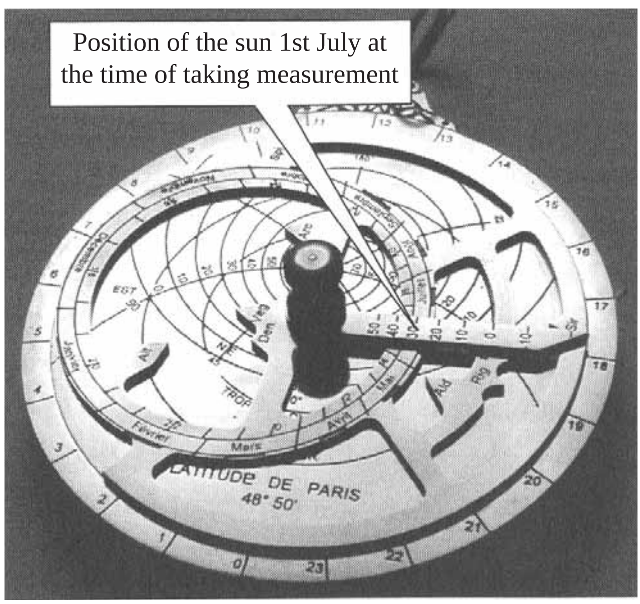


Astrolabe spider. Figuring the points of the very bright stars, the position of the sun corresponds to calendar dates.

To measure the time

The first thing for the observation of the sky is the measurement of time. The position of the sun in the sky gives you an idea of the time. You know that at midday (noon), it reaches its maximum height. The position of the night stars also gives us the hour; shepherds and sailors know this well. This will be the first function of the astrolabe that provides the time using the angle of the sun's height or one of the stars figuring in the spider and previously measured. The sky seems to make a rotation in twenty four hours, the edge of the astrolabe is also graduated in twenty four hours, with 12 hours (midday) to south. Let us take two examples (it is easier to follow these examples with the aid of an astrolabe model, such as you can make, from directions on the website for this book, or by photocopy of pieces in the appendix of the pedagogic text.)

Let us suppose that on the afternoon of the 1st July, you measured the sun at a height of 20º. You look at the astronomical face of the astrolabe and turn the spider to the date 1st July (the position of the sun in relation to the stars on that day) on the height circle of 20º. As there are two possible positions (and two instances of the day where the sun is at 20º altitude), in the west half of the tympanum you can measure for the afternoon. The sky is now in position, such as it was when measured. A mobile needle leads to the position of the sun (for date 1st July) will indicate the time (solar) on the edge of the instrument. If you are at the latitude of Paris (using the corresponding tympanum), you will read 17:45 on the edge.

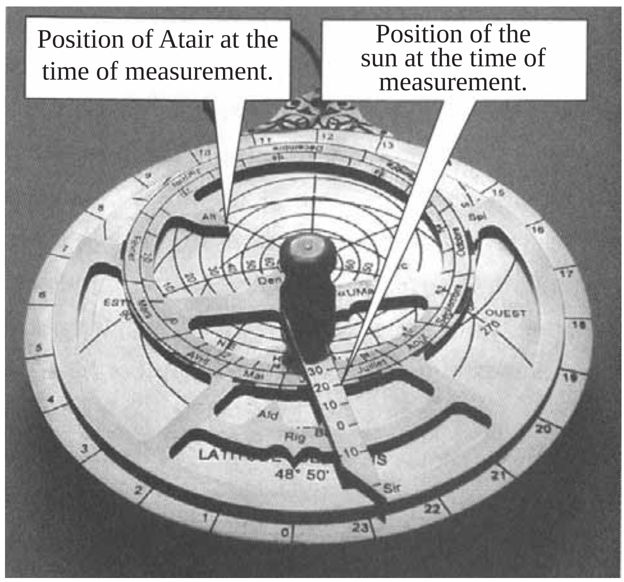


Determining the time of day

The procedure is analogous at night. Let us suppose that it is the night of

1st July and that you have measured the star Altaïr at 40º height in the east half of the sky. You turn the spider to the desired position in the sky, that is to say, the point indicating Altair is at 40º on the circle on the east side. The time (solar) is given by the sun which, at night, is beneath the horizon. You set the needle on the date 1st July, corresponding to the position of the sun under the horizon, and the time is indicated on the side of the instrument. If the tympanum is that of the Paris latitude, you will read the solar time as 22:50.

The use of the astrolabe for telling the time, as well as for the resolution of some astronomical or astrological problems, as the determination of the duration of day or astrological ascent, is presented in the oldest trait of the astrolabe that we have seen, as written in Alexandria about 550 in our era by Jean Philopon, called the Grammarian. There is still nothing more than, on the other hand, on the possible uses of the astrolabe to find position or for topography, than as written in a treatise by the Bishop Sévère Sebokht written in Syria in the VII century. You have to wait for the introduction of the astrolabe into the Islamic world, where, it is said, the instrument found a favourable home, and to look in the treatises of al-Khwârizmî to find several new innovations that we have already pointed out.



Tympanum of the astrolabe for the latitude of Paris (48º50’)

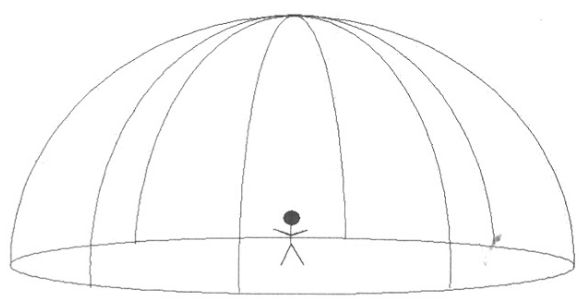
Al-Khwârizmî and the astrolabe

The mathematician and astronomer al-Khwârizmî is famous as being the founder of algebra. It is less well known that he was also a great astronomer, who was interested in practical questions and with instruments such as the astrolabe[3]. One knows very little about the life of Abu' Abdallah Muhammad ibn Musa al-Khwârizmî (born before 800 died after 847). His epithet "al-Khwârizmî" seems to indicate that he originated in the province of Khwarizm, today called Uzbekistan. Under Caliph al-Ma'mun, who reigned from 813 to 833, al-Khwârizmî became a member of the famous "House of Wisdom" (*Bayt al-Hikma*) founded in Baghdad by Harun al-Rashid, father of al-Ma'mun and of *Thousand and One Nights* fame.

In it is this sphere that the principle treatises were written: his book of algebra, *al-Kitab al-Mukhtasar fi hisab al-jabr wa-l-muqabala,* his book on Indian calculus, but also the astrological tables, Zij al-sindhind, inspired by the Indian tables, as well as the geography provided in the lists of longitudes and latitudes of the places. Al-Khwârizmî is the author of two works on the astrolabe, one on the making of the instrument, the other on its usage. In the latter, there appears for the first time, to our knowledge, new uses and the use of azimuth and the square of shadows.

The lines of azimuth and orientation in space

The arcs of azimuth traced on a local sphere link the zenith to different cardinal points. The angle of azimuth that the astronomers measure from the south (sailors and topographers, from the north) give, with the height angle, the local coordinates of objects in the sky.



Equal arcs of azimuth on a local sphere

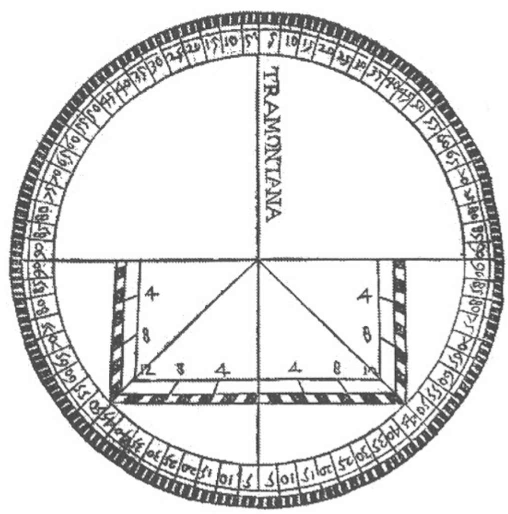
Added, on the tympanum of the astrolabe, the equal arcs of azimuth allow for orientation. They become an important discovery for voyagers, but also for the faithful who must, for their prayers, know the direction of Mecca. This orientation is more precise than that given by a compass, the deviation between geographic north and magnetic north is, in effect, variable, in time as well as distance.

In his treatise on the astrolabe, al-Khwârizmî describes how to use the instrument to determine the azimuth of the sun. Let us take an example. Suppose that you want to find out the position of the sun on the 1st April on the latitude of Paris when it is 14:30 solar time. You place the needle of the astrolabe at 14:30, then pivot the spider in a fashion to lead to the niche of the 1st April under the needle. You can see that the sun, that is to say the graduation of the 1st April, is situated on the south west line of azimuth. At this moment, the sun indicates therefore the south west.

You can then return the astrolabe and use the back of it to take your bearings. You can use the graduations in degrees found on the edge to indicate the directions and the alidade will serve as the needle, just as a compass (except that it shows true geographic directions and not the magnetic directions of the compass). If you note that the graduated angle situated on the suspended ring represents the direction south, south west corresponds to south west at 45º to its right. Then the sun is in the south west direction, you place the alidade on the graduation 45º and, keeping the astrolabe horizontal and without touching the alidade, you turn it until the alidade is in the direction of the sun. The azimuth of the sun is then in place and the astrolabe shows the direction. All the azimuths are correct and you can, by turning only the alidade, check out the details of the countryside in the selected azimuths.

The square of shadows

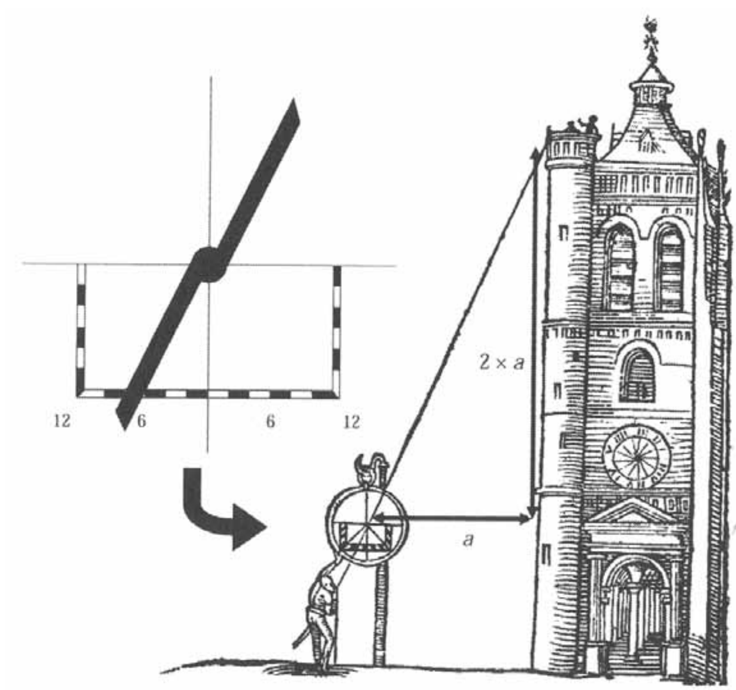
The square of shadows (usually double square as the figure shown, of which the sides of the squares are 12 units and are graded 4-8-12) is usually shown on the back of astrolabes dating from the IX century. Al-Biruni reports that some attribute its invention to al-Khwârizmî. In fact, al-Khwârizmî's text, which in his treatise starts by: "If you



Double square of shadows on the back of an astrolabe (drawn by Cosimo Bartoli, Del modo di misurare/ on the way to measure, 1564) want to know the shadow of the height and its construction", note first of all the astrolabe's square of shadows.

The name "square of shadows" makes reference to analogous measures that are obtained with the help of the shadow of a baton, a gnomon (the arm of a sundial) planted vertically in the soil. The preceding figure represents a gnomon measuring 12 units, but that is arbitrary (this is also in al-Khwârizmî's text.)

Suppose that, on a sunny day, you can measure the height of a building because you can measure the shadow on the ground. The sunbeams are considered to be parallel, know them, to know the height of the building, as you know the relation between a vertical thing and its shadow. Take a baton of 12 units and hold it straight vertically. Measure its shadow. If, for example, it is 6 units, you have a relation of 12/6 =2. You can deduce from that, that the height of the building is equal to twice the length of its shadow.



To measure a tower (drawn by Dominique Jacquinot, *The use of one and the other astrolabe particular and universal,* 1625)

The method of the shadow is, however, inaccurate. You must hold the astrolabe perfectly vertical and to aim at the building through the pinnules of the alidade. This will be indicated on the square of shadows, the relation between a vertical measurement and a horizontal measurement, e.g. 12/6 if she falls on a graduation of 6 on the square. It is necessary to measure on the ground the distance separating the point aimed at and the foot of the building, then to calculate in the way as indicated on the astrolabe, without forgetting to add to it the distance between the ground and the eye of the observer.

The sine quadrant

The sine quadrant *(al-rub'al-mujayyab)* is an important graphic on one of the quarters of the disc on the back of the astrolabes and which allows us to find the sine and cosine of the angles, but also, with the help of the alidade, of other more complex trigonometric functions as this gives the declination of the sun in the function of its longitude (the declination of a star is one of its equatorial coordinates and the longitude of a star is one of its ecliptic coordinates). We are now coming into details that are too technical; the essential thing is to understand how to work out the graphics, which provide the visual solutions to complex calculations, alongside the development of trigonometry by the savants of Islamic countries (noting cosines, tangents, relations and formulae). The astronomer of the XIII century al-Marrâkushî attributed al-Khwârizmî as its father, naming the sine quadrant al-jayb al-Khwârizmî, this is to say, "the sine quadrant of al-Khwârizmî", besides, it seems, that the first description of this graphic, which is found in the treatise *On the construction and use of the sine quadrant* of al-Khwârizmî.

After al-Khwârizmî, the great savant al-Bîrûnî (973-1050), in his *Treatise on the astrolabe*, adds to the tympanums of the instrument the dawn/twilight line under the horizon (the day starts to appear when the sun is on this line), as well as other lines indicating prayer times for Muslims. However, the most notable invention after the innovations of al-Khwârizmî is that of the universal astrolabe.

The universal astrolabe

To obtain an astrolabe "universal", you try to have not more than one tympanum, and therefore one instrument for all latitudes.

The exact origins for the “universal” astrolabe are not certain, but the invention of the instrument was made in Andalusia. In the XI century, at Toledo, two contemporary astronomers travelled with one universal astrolabe obtained by stereographic projection. The first, little known, is Ali Ibn Khalaf, who left us this testimony:

“ [. . .] it happened that I knew how to make an instrument [astrolabe] for the entire world, which only has one tympanum and one spider. I have given it the name of universal horizon, and I do this for my master the king al-Ma’mun [of Toledo] (1037-1074) and I have made this book [. . .].”[4]

It happened due to a tympanum that was engraved with the result of a stereographic projection in particular. Technically, it happened from a stereographic projection on the leakage plan of the solstices and of which the projection pole was situated at the vernal point (if this definition is too technical, it is important to understand that the universal astrolabe does not represent the sky as well as it appears and that, for this reason, will not replace the classic planispheric astrolabe). With its single tympanum “universal” turning a spider divided into two parts, a half represents a map of the stars, the other half a tile of meridians and parallels.

More famous, even in his time, the second astronomer was al-Zarqâlî (died in 1100), born at Cordoba but he lived mostly in Toledo. A self educated person, who made his living to start with by making the instruments. Al-Zarqâlî conceived his “saphea” (the term *safiha*, in Latin *saphaea*, design the tympanum of the astrolabe) with the same stereographic projection as ibn Khalf, but substituting to the spider an alidade furnished with a cursor that has a small arm. From his treatise on it Safiha az-Zarqâliyya, there are many translations of it. In 1263, Profatius de Montpellier (Ibn Tibbon) in composing, with the help of Jean de Brescia, a version in Latin from a translation in Hebrew, This astrolabe will be “re-found” five centuries later by Gemma Frisius at Louvain, under the name astrolabe “catholic”, that is “universal”.

The destiny of the astrolabe

The astrolabe is without doubt the scientific instrument that has had the longest career, from the end of Antiquity until the start of modern times witness what each civilisation has brought for scientific improvement. The savants of the Islamic countries have made a multifunctional instrument which furthered the resolution of the astronomical questions and the measurement of time, permitting us to plot our location, to make maps, and to make many types of trigonometric calculations. The treatise of the astrolabe by as-Sufi (903-986), which, with its 386 chapters, is considered exhaustive, shows more than a thousand possible uses. From the end of the XVII century, the astrolabe will be passed over and gradually replaced, for its different uses, for precision timepieces, the sextant (to measure the height of stars at sea), the theodolite with a visual aiming device (for topography), and as an instrument for calculation.

The astrolabe has been credited with immense powers. In revealing them, it ought to guess the future and cure illness. It does carry a true pedagogic power. That to teach us the history of science and what has been done, but also to understand, and to try, some principles of astronomy and mathematics, can we conclude in quoting the *Treatise on the composition and fabrication of the Astrolabe* by Johann Stöffler, who has said in his lectures “above any doubt, there cannot be anything as enjoyable, where pleasure is not received to learn about the astrolabe; to which this will serve as a vocabulary to those, who study the discipline of mathematics, for the reason of the noble and high inquisition of its innumerable uses.”

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The astrolabe
or the heavens in your hand

Requirements
The succession of day and night and the movement of the sun in the course of an entire day, seen from the Earth, are linked to the rotation of the Earth in 24 hours.

Objectives
In the course of one night, you can see, from the Earth, the stars turning on their solar Pole; this movement is linked to the rotation of the Earth on her polar axis passing by the solar Pole.

In the course of 24 hours, as the sun goes from east to west, its height varies and it culminates at midday in the direction of the south. This course of the sun in the sky, seen from Earth, varies according to the seasons.

In the course of a year, you can see the sun moving through the zodiac constellations (also called "ecliptic constellations" for they are contained in the rotation plan of the Earth around the sun): this movement observed from the Earth is linked to the revolution of the Earth around the sun.

With reference to the programme of sciences and technology of year 3 primary school
"The sky and the Earth: the movement of the Earth around the sun; the rotation of the Earth"

From the IV to the XVII century, the astrolabe has had multiple applications, in particular to determine the time, of day and of night, to reach the height of the stars or the sun in the sky, for gaining our bearings. Invented by the Greeks, then perfected by the savants of Islamic countries, this instrument retains amongst others a special importance for Muslims as it allows them to know the direction of Mecca for their everyday prayers (see the historic text for more details).

Research in text books follows on, from the making of an astrolabe model allowing children to familiarise themselves with the history and the different parts of this instrument. With the help of this model, we are going to make, as did al-Khwârizmî with Nabil and Fadila (the master will read the text in class for the children), to introduce them to the use of this instrument. The first concerns the astronomic use of the astrolabe, “the taker of the stars”, the second its use to determine the height of a tower, for example. Altogether the activities require ten or twelve meetings but several of them are independent.

Text book research

The pupils are encouraged to research the information available about the differences of the astrolabe; By whom was it invented and then who perfected it? Who was it for? What are its different elements?[1]

You could make a chronological freeze citing the Greek periods the Islamic and show that this instrument has been used for a very long time.

The information gathered could be recorded in an exercise book.

Making an astrolabe

The text book research and the presented animation on the project site allow the pupils discover the different parts of the astrolabe. You suggest to each pupil to make their own instrument from these different pieces of equipment.

Materials

The pupils are each given different photocopied parts (the back and front of the mould, tympanum, needle, and alidade) and the photocopied spider as a transparency (see appendage). They should also have an index card, and a glue stick, two eyelets, a paperclip, a Parisian clip and a piece of straw 5cm long.

Assembly

1. stick the back of the mould on the index card and cut out the disc;
2. cut out the face of the mould and stick it on the other side of the index card;
3. cut out the tympanum and stick on the face on the front of the mould, whilst aligning the south direction with the 12 notches (graduations) of the mould
4. stick the needle and the alidade on the index card then cut off;
5. cut out the outline of the spider following the dotted lines (on the transparency);
6. superimpose these in order: the alidade, the mould (tympanum on the upper), the spider and the needle, and secure these with the Parisian clip in the centre;
7. stick a piece of straw on the length of the alidade
8. punch the suspension hole, and reinforce it with the eyelets
9. put a paper clip in the hole

Once the objects have been made try them out as a group so that individual errors can be ironed out.

The rear face of the mould

Here you can see the twelve months of the year represented in a circle (anticlockwise); for each month (with small gaps), you read the name of a constellation and the children can easily recognise the names “signs” of the zodiac. You can also see the half square on which the word “shadows” is written: what does it mean? The alidade turns and seems to aim thanks to the straw: what is it for?

Front face of the mould

There are many circles drawn on the tympanum; one of them in particular is graduated from 0 to 90º (even if the pupils do not know about the measurement of angles, you can tell them that a right angle has 90º). You read: “latitude of Paris”; this astrolabe can therefore be used in mainland France, but it would be inaccurate at the North Pole or the equator, as was stated in the animation. The exterior ring is graduated in twenty four hours.

Spider

This piece has marks which represent the brightest stars in the sky (see animation); these stars are reached by the first letters of their names and we are going to try and identify them whilst observing the sky map (see appendage) the brightest stars.
— “Sir” for Sirius, the brightest star in the sky,
— “Ald” for Aldebran;
— “Rig” for Rigel, and “Bet” for Betelgeuse, the brightest two stars in the constellation of Orion, which is visible during winter;
“Arc” for Arcturus;
— “Den” for Deneb, “Veg” for Vega, “Alt” for Altair, the three stars of the summer triangle that you can see high in the sky during this season.

This exercise allows the pupils to familiarise themselves with the sky whilst recognising some of the stars and constellations with the aid of the sky map which is reproduced from a plan “the sky dome” thought out by Nabil and Fadila. To use the astrolabe, you have to know the sky and the stars for it is by the latter that we get our bearings or to know the time at night. The master can organise an observation of the sky to complete this work.

After the reading of the text for children one encourages the pupils to comment, and ask questions, the passage in which Nabil and Fadila try out the movement of the stars during the course of the night and the immobility of the Polar star. The presentation of a photo of the night sky taken with a long exposure lets them visualise this movement of the stars around the Polar star. The master will help the pupils to interpret this phenomenon by the rotation of the Earth on its axis: the Polar is fixed for the terrestrial observer as it is on the same axis rotation as the Earth. You can use a terrestrial globe pierced through by an axis: when the globe turns on its axis, the points of the axis are stationary.

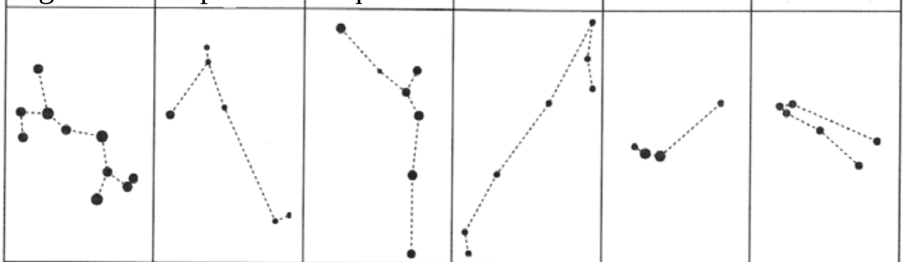
Wondering about the movement of the sun in the course of a year on the basis of the stars

We will look now at the position of the sun on the astrolabe; the animation tells us that it is represented by a “calendar” all around the spider: we effectively observe a graduated circle in months on the spider. Also, in the course of the months, the sun moves and makes “its tour of the sky” in a year. This observation can be the object of a first question: “Why are the stars always in the same position on the spider (the marks of the spider) whilst the sun moves in a circle from month to month?”

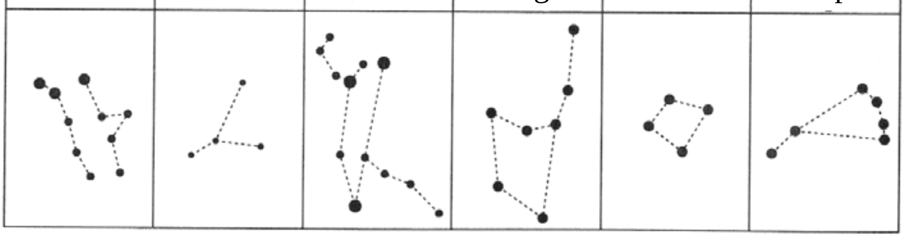
The pupils observe again, as on the back of the mould, the different months represented in a circle on the spider. The master invites the pupils to observe the same calander in the sky map: behind each month, reached by its number, you read the name of a constellation of the zodiac. For example, for the month of June (6), you find the constellation of Taurus and this therefore gives the direction that you can find the sun in June. In July (7), Cancer etc. Also, the sun coincides each month with a different sign of the zodiac. In observing the sky map and with the help of the drawings of the zodiac provided in the appendage, the pupils can make a table as: for each month, they stick the drawing of the constellation corresponding with its name.

Notes for the master: the ecliptic plan, the plan for the orbit of the Earth around the sun, passes by a certain number of constellations called “constellations of the zodiac” or the “ecliptic”[2]. You ask the pupils to use a map of the sky and not the astrolabe to fill in the table. They perhaps remark on the gap of about a month with the names carried on the rear of the astrolabe’s mould. This gap is explained by the fact that the signs of the zodiac have been defined in the Vth century A.D. and that the sky is modified according to the procession of the equinoxes (slowly changing direction of the axis by the rotation of the Earth). Furthermore, the zodiac had been divided into twelve equal parts, in order that the constellations have very different presentations. Actually, the signs of the zodiac only have a distant relationship with the constellations of the zodiac, but this difference will not be explained to the children.

January	February	March	April	May	June
Sagittarius	Capricorn	Aquarius	Pisces	Aries	Taurus



July	August	September	October	November	December
Gemini	Cancer	Leo	Virgo	Libra	Scorpio



Position of the sun each month in relation
to the constellations of the zodiac

The pupils can stick this table in their notebooks and perhaps elaborate on the text. For example: “This table indicates the name of the constellations before which the sun passes each month; also, in June, for a terrestrial observer, he is in the constellation Taurus; in July the sun seems to move to the east and is found before the constellation of Gemini, and so on. In a year, the sun comes back to its initial position.”

The master encourages the pupils to solve the problem (“Why does the sun move in the course of a year on the basis of the stars?”) and to understand what actually happens. For this, each group of pupils gets twelve labels, prepared in advance, representing the constellations of the ecliptic (see the document in appendage). They are invited to place in a circle on their table (beware, a glance at the astrolabe will show them the order of the constellations per month, but in anticlockwise fashion). Then, they will have to place the sun (represented by a ping-pong ball) and the Earth (a small globe, a crayon end perhaps) in their respective positions for the month of June and to imagine what happens in the months (from June to December, then December to June).

For this, you have to reflect on the position of the sun and the Earth in relation to the stars; the sun is much nearer to the Earth than the stars! Then, you have to take note of the data in the table; in June the sun coincides with the constellation Taurus (that is to say that the sun is found in the direction of this constellation for the terrestrial observer). Therefore you cannot see Taurus in this period for this constellation is in the same position as the sun in the sky that is in daytime; on the contrary, at midnight, the same month, you are "opposite" the constellation of Scorpio, which is still visible in the sky.

Most of the groups will in all likelihood place the Earth at the centre and make the sun turn around the Earth in a year to explain how the sun coincides each month with a different zodiac constellation.

A collective exchange will allow the confrontation of the geocentric model adopted by the majority of the groups, and the heliocentric model. If all the groups think only the geocentric model is correct, it will be necessary to ask them all to explain why. As soon as the pupils realise that they have the sun turning around the Earth, they rapidly react, they realise that it is an error. In effect, the majority of them already know that it is the Earth that turns around the sun and not the reverse.

The confrontation of the two models is very interesting, and it is necessary to explain to the pupils that both are pertinent. But that they correspond to different view points: the one of the terrestrial observer (for whom the sun makes its tour of the sky in a year) and the one of the observer who is placed on the sun (for which it will be the Earth that makes a revolution around the sun in a year).

The sun's movement during the course of a year on the constellations of the zodiac is therefore interpreted as an "apparent" movement, as the sun's movement from the east to the west in the course of a day, that the pupils have already studied.

To tell the time (or get your bearings) with the astrolabe

"To take the stars" with the astrolabe, this signifies reaching their height, that is to say the angle between the direction of the star and the horizontal plan, this angle being understood as between 0º (when the star is on the horizon, therefore fully visible) and 90º (when it is at its zenith, that is vertical in comparison to the observer). Measuring angles is not carried out at elementary school; usually, children of average ability can use the protractor reproduced on the astrolabe, in the same way that they can use the graduated dial of the compass. Beware: you have to remember that for a child, the height of the sun (or of a star) is assimilated most often at a distance and not at an angle. The animation allows the introduction of a reflection on the nature of this grandeur and gives a good introduction the notion of an angle.

The first activity consists of "taking the sun", that is to say to take the height of the sun at several times in the day with the astrolabe, held vertically, to answer different questions: "At what time of day is the sun at its highest in the sky? On what season? How can we measure its height with our astrolabe?" The master can let the children formulate some questions before letting them see the animation. The children will use the astrolabe and will understand the principle: You need to point the astrolabe at the sun and pivot the alidade until the sun's beams enter the straw. You can then obtain the sun as a round light. Beware; the pupils still cannot fix the sun, through the straw.

The making of a graphic, (the changes in the height hour by hour) show that the sun is visible in the sky for 14 hours in summer and 13 hours in winter (it is therefore the solar midday and the sun is in the south direction, this can be checked with a compass) before re-descending in the west.

This could be done several times a year, with readings taken every two hours, so that the children can note whether the sun is higher or lower in sky according to the season, but that it always culminates in the southerly direction at solar midday. Beware, contrary to what the children usually think, the sun never passes to the zenith over mainland France, even on the 21st June when it is at its highest point (its height is about 65 to 70º according to the latitude).

In order to explain the method, the master could provide the pre-made graphic for a certain date and ask the children to work out the time from the value of the given data - the height of the sun; with the graphic, you have two hours, (one a.m. the other p.m.). For example, the 1st July (see the graphic on the website dedicated to the project), if the sun is at 20º above the horizon, it is 06:15 if the sun has just risen in the eastern horizon, it is 17:45 if it is descending in the west. Be aware, there are published solar times, for the latitude of Paris.

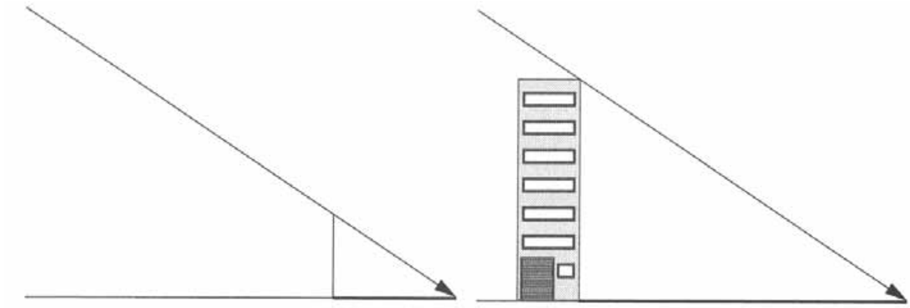
With the astrolabe, no need to trace all the graphics! The determination of the time when you know the date is much easier: it is sufficient to turn the spider to the date 1st July (position of the sun in relation to the stars on that day) on the height circle of 20º. Be aware, there are always two possibilities (a.m. or p.m.) With the needle set on the 1st July you can read the time on the side of the instrument: if it's the afternoon it is 17:45.

Several exercises of this type allows the pupils to familiarise themselves with the use of the instrument. It is always interesting to compare the results obtained with the astrolabe to the graphic.

At night, you can proceed in a similar manner, but when you see the bright stars, you can tell the time. It is for this reason that it is very important to know the sky well when you want to use the astrolabe.

How to measure the height of our school with the astrolabe?

To measure the height of a tree or a building, one method is to measure the length of its shadow on a sunny day. The measurement of the shadow of a sundial (baton placed vertically) gives us the value of x between its length and its shadow. As the sun's rays are parallel between them, the relationship is the same between the height of the building and its shadow: knowing the length of this shadow, you can easily deduce the height of the building.



Height of the building = the length of the shadow of the building x x.

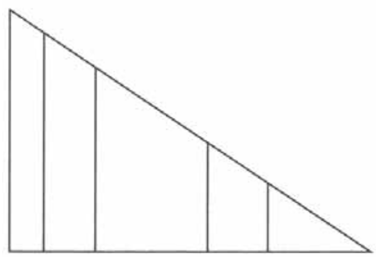
For example, if the sundial gnomon is twice as big as its shadow, x=2, the height of the building is twice as big as the length of its shadow.

For the pupils, you can make a challenge: "The astrolabe helps us to measure the height of the sun, but could we use it to measure the height of our school?"

The term on the astrolabe: "square of shadows", will, without doubt, encourage the pupils for a first time to try a method using the shadow of a baton standing in the ground.

Each group should be equipped with a small board and a flat headed screw, but of a different length for each group. The children go into the sun, see the shadow of their screw and measure the length of it. The pupils record their results in a table of two columns (length of the screw – length of the shadow) in their notebooks. The results are collectively analysed, and the children note that the longer the screw is, the longer the shadow is; they may notice a proportional relation between the two lengths.

The pupils then draw the different experiences on a scale, of the profile. The comparison of these schemas show that the triangles formed by the screw, the shadow and the sun rays, even if they are of different sizes, can be stacked: the angles between the ground and the sun rays are equal. It is this angle that is called the “height of the sun”!



Similar to this method of shadows, the back of the astrolabe carries a “square of shadows”, which allows you to determine heights by design.

The animation encourages the pupils to use the astrolabe to determine the height of a building. But how do you use the square of shadows? The children are invited to aim, from the playground, at the top of several buildings (roof of the school, top of a bell tower, the top of a water fountain) through the straw. They are going to note that the alidade is more or less slanted and that its position can be reached by a number on the square of shadows; the master asks them to note this number.

The comparison of the measurements shown is different, for the same building, according to the place where they were taken: “When I aimed at the roof of the school, I got 2 when I was near the building, and 6 when I was further away.”

When keeping the same position, the children noted that the taller the building, the more the square of shadows gave a small value: “For the school I got 12 and for the tower, which is higher I got 4.”

If these indications did not give a height directly, what use were they?

To help the pupils to understand the principles of the square of shadows, the master marks the wall of the school two marks corresponding to the heights of 6 and 12m ideally (otherwise 3 and 6m).

The pupils should find where to place them as to the indications of the alidade (4,6,8,12) for example and for each of them, to measure the distance between the aimed position and the building with the aid of a decametre, and a surveyor's chain or a rope that has a mark or a knot every metre.

The class as a group will make a table of measurements. To the nearest measurement, the results we obtained were as follows:

Alidade reading	Distance to the building Marked at 6m high	Distance to building Marked at 12 m high
4	2m	4m
6	3m	6m
8	4m	8m
12	6m	12m

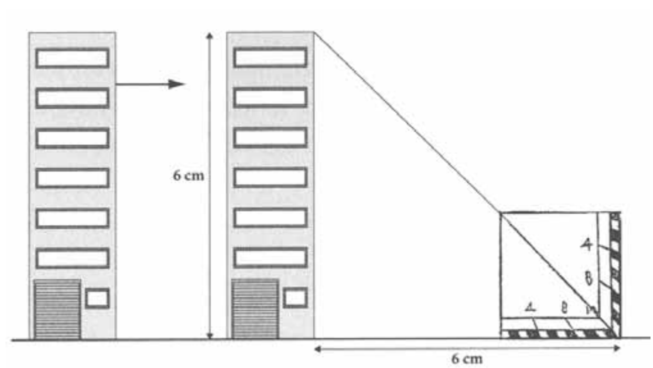
The children remarked on the graduation 12; "If I read 12 on the astrolabe, I am a little nearer to a distance of the building equal to its height." Also, if one does not know the height of the building, it suffices to measure the distance to the building to know its height. If the astrolabe indicates 6, the distance is a little nearer equal to a half of its height.

Always, these remarks would not have a status of hypothesis for the values measured would probably contain some important errors. You can reflect on the causes of the errors and show that they have three origins:

— The instrument: our label is cardboard and may be deformed, there is some play on the alidade. . .
— Handling: the rope is not always taut. . .
— The taking of the measurement: the ground is not very flat. . .

Note for the master: It is necessary to remember the height of the children, this complicates matters, it is often a good point to ask them to sit down when aiming their instruments to reduce the problem.

The making of a diagram could help to confirm the hypothesis and to simplify, you are supposed to take the reading (aim) from ground level. The pupils are therefore invited to make a diagram of their experience. They compare their findings between each other, and if necessary, to the drawing on page 79 of the historic text. A profile diagram is also made collectively. The children then arrange several reproductions of the square of shadows and of several rectangles representing a building of 6m high (bandelet 6cm long). They ought to position the bandelet (building) for each indication of the astrolabe (see figure for the graduation 12)



The pupils can then measure, on this diagram, the distance to the building and put it in a table of measurements. The errors will be less important than the measurements in the yard and the results table easier to analyse.

Length of the side of the square of shadows[1]	Alidade reading	Building height	Distance between the point of aiming and the building
12	4	6m	2m
12	6	6m	3m
12	8	6m	4m
12	12	6m	6m

The children noticed the equality of certain relations: for example 12/6=6/3, 12/4=6/. . They could perhaps come round to discovering the general rule:

The relation between the length of the side of the square of shadows (12) and the indication on the alidade is equal to the relation of the height of the building (6) and the distance between the point of aiming and the building. The master will place some different targets on a wall and the pupils have to determine their height with the square of shadows. The most simple method is to be sure to set the alidade on 12 and move yourself until you see the target, but you could point out to the children that this method will not always be possible.

The pupils could think up another method of operation that they could record in their notebooks, and test it out in another lesson.

Conclusion

The different activities proposed have given the pupils the opportunity to familiarise themselves with the astrolabe, to discover its value and the variety of its uses in two very different ways. Beyond its uses in the sky, the pupils have worked with numerous different mathematical methods: the notion of angles, measuring distances, the making of tables of measurements, tracing and formation of graphics. . . They have been encouraged to solve diverse problems and to resolve by different ways of investigation: observation, experimentation, making a model, and labelling.

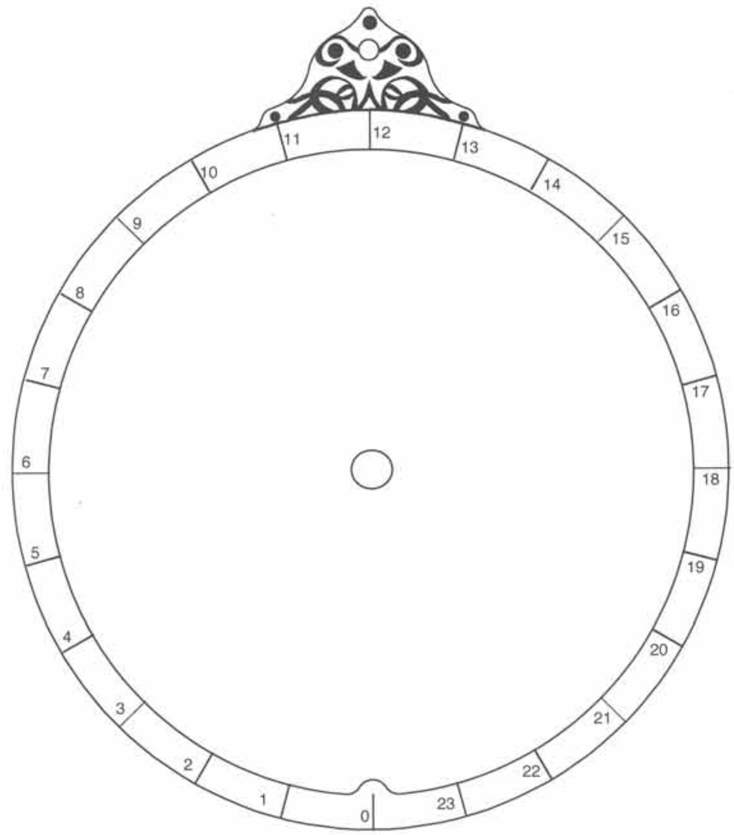
Notes:

1. It is sufficient to discover the different parts of the astrolabe, not to study in detail the circles on the tympanum of the astrolabe

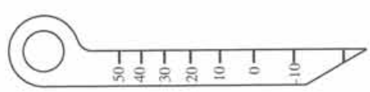
2. In fact there actually exist 13 constellations of the zodiac unequal. For simplicity we only take count of 12 corresponding to the traditional zodiac, Ophiuchus, is the other.

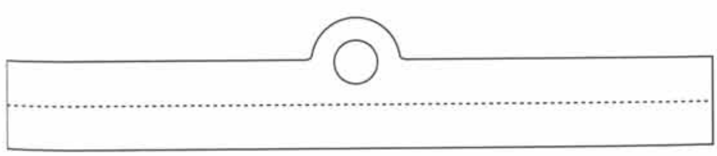
3. This column will be kept for ease of discovering the equality of some relations.

Appendix



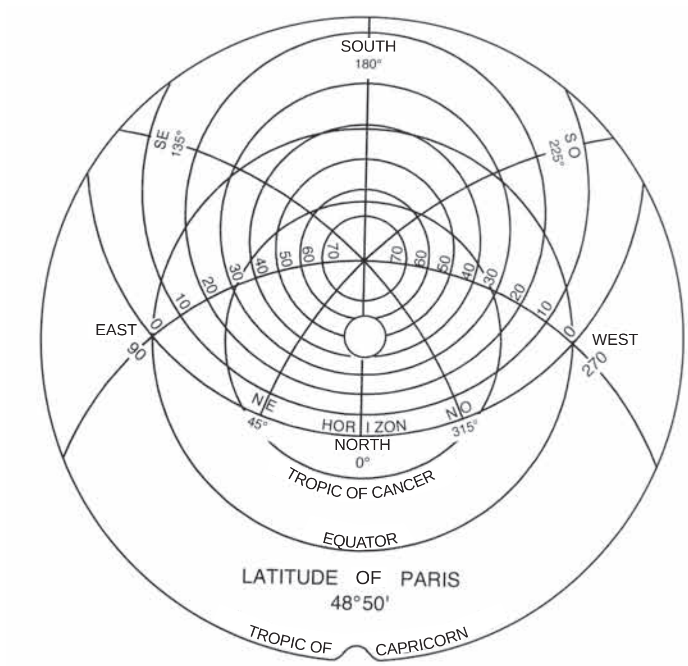
Mould face and ruler



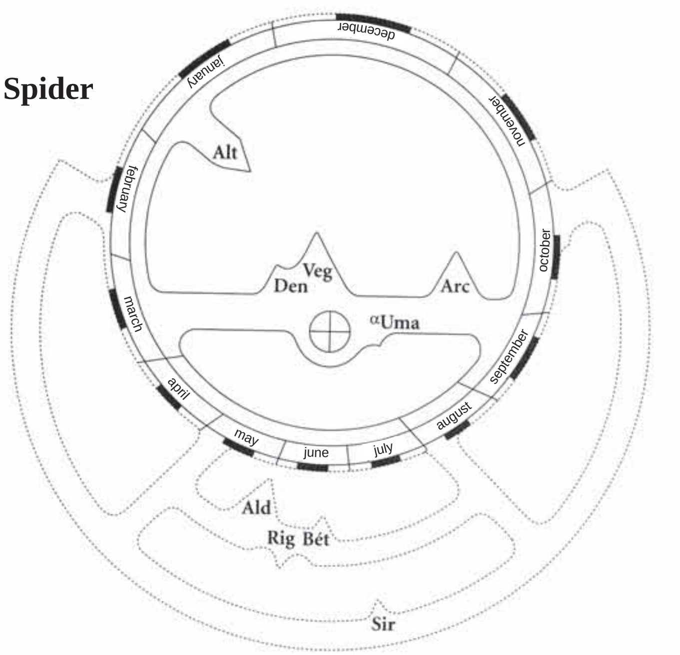


Alidade

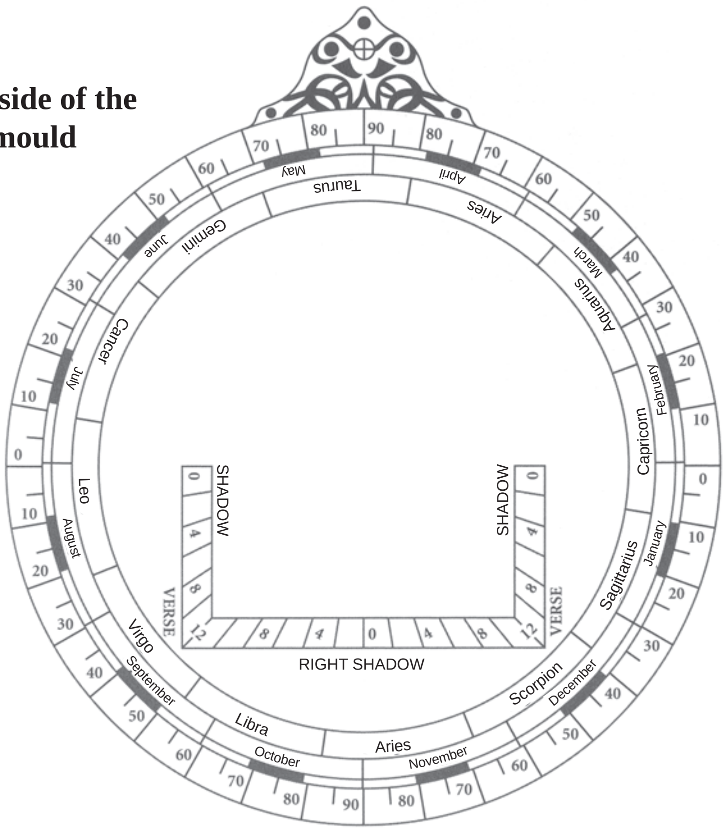
Latitude of Paris

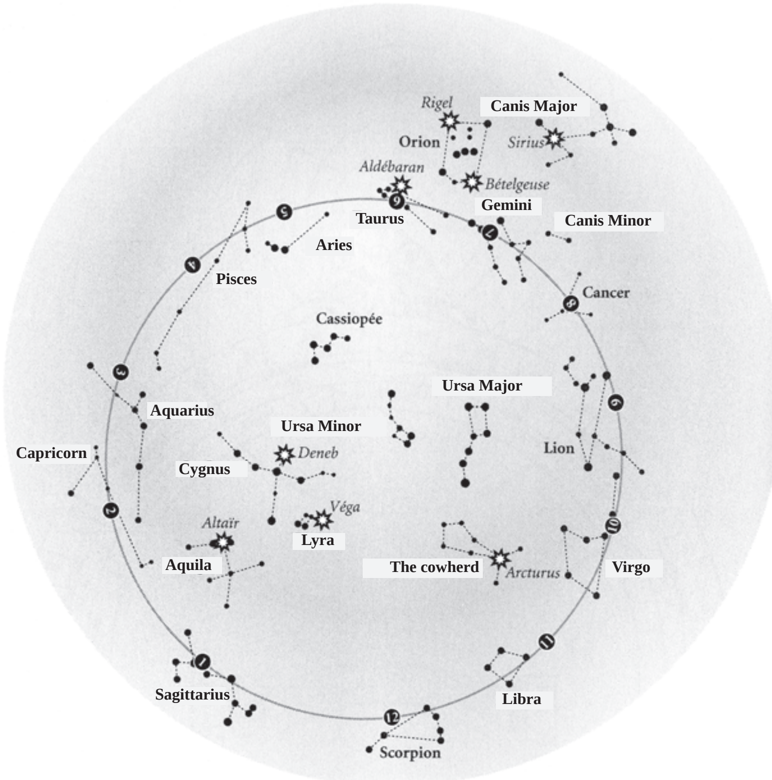


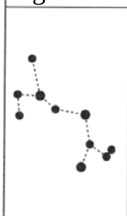
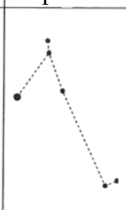
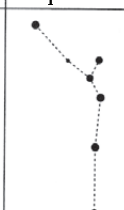
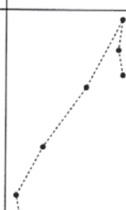
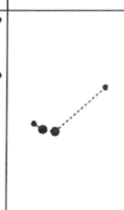
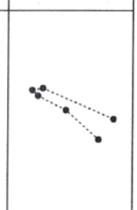
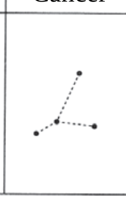
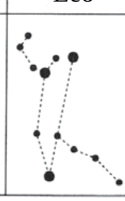
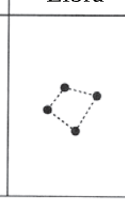
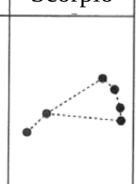
Spider



Backside of the mould





January	February	March	April	May	June
Sagittarius	Capricorn	Aquarius	Pisces	Aries	Taurus
					
July	August	September	October	November	December
Gemini	Cancer	Leo	Virgo	Libra	Scorpio
					

The favourite game of Nabil and his sister Fadila was to resolve problems which they observed as they occurred around them, or inside them. They were more passionate about them than others of their time; a little magic was about them, just as the day when they were trying to capture the stars. . .

The sun was just about to set. Lying by the riverbank, Nabil and Fadila watched the stars light up one by one in the sky, as if signs that you could guess their disguises. Fadilla broke the silence in a dreamy voice:

— The sky was becoming darker, you could see more stars. I wonder if anyone has tried to count them before. . .

Then she became more animated and sat up to look around her better:

— Nabil, where has the moon gone?

Nabil groaned. He liked to look at the show the stars put on and had no inkling to move, he softly replied to his sister:

— It has to sulk, just like you sometimes!

Fadila was vexed:

— That's nasty! The moon has not yet risen! You believe maybe, that I do not know that the stars are on tour during the night?

Encouraged by the fact that he had annoyed his sister, Nabil picked up his train of thought and said:

— And you know, then, that in the middle of them is one star that does not move?

Fadila was surprised by this question, but she quickly reacted:

— If there is one, it will be easy to find! All you have to do is make a drawing of the stars, and return a little later and make another, compare the two and see which star has not moved!

— It will not be easy to draw the dome of the sky on a flat piece of paper! And how can you be sure that it will be the same star on each of the drawings?

Under the cover of his teasing, Nabil asked Fadila some questions that he had wondered about himself. And Fadila, who was making good of her sulk, thought about them. Finally she finished by saying:

— If you made a scaled model of the sky, it would be as if you had captured the stars. . .Fadila was interrupted. From the sky, there overflowed a long file of bearded people wearing turbans and wrapped up in long coats who all had suspended from their hands a metal disc covered in inscriptions and had circles and stalks that were turning under their fingers. There was a continuous murmuring about them: " . . . aim . . . find the height of the star . . . know the day and the hour . . . calculate . . ."

Nabil and Fadila forgot their quarrel and called out to them in unison:

— Please, would you teach us how to use your instruments?

The men mirrored themselves in a circle, conferring with each other, then one of them spoke:

— I am Abu Ja'far Muhammad ibn Musa al-Khwârizmî and I speak for all of us. We are all agreed to initiate you with the astrolabe, but only until the moon appears for later on we will be too busy. Come now!

What happened next has not been passed on to us, it was a long time ago, the memory is lost! It only remains that the astrolabe, the "taker of the stars" has been around Islamic countries for a long time. It lets you know the time during the night, to find your bearings in the desert, and many other operations too. And in one manner or another, as the astronomers grouped themselves around al-Khwârizmî, they introduced Nabil and Fadila into the astrolabe and its use, they will tell everyone today its secrets if they want to know them. In one way or another. . .

Symmetry

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Science and art in the land of Islam: an example of symmetry

Bedazzlements

Look at this sculpted frieze on a wooden panel and conserved in the museum of art, in Cairo, (see fig 1). We are going to see, below, the same pattern: a star and a polygon, repeated almost identically at equal intervals by transfer. This design is strongly geometric. Let us now look at this panel incrusted with ivory patterns coming from a wooden door which is in the same museum (see fig 2). Here we also see the geometric patterns appearing: the stars have fourteen arms. The right part of the door if traced on paper and put in front of a mirror is a copy of the left, and it is the same with the upper half and lower half. In fact, you have to study the panel in quarters. Take this calligraphy (see fig 3): it is symmetric, as is this partition (see fig 4). If we were to consider this assembly of ceramic squares, furthermore the different decoration by different material, it is the repetition of a hexagonal tiling that retains

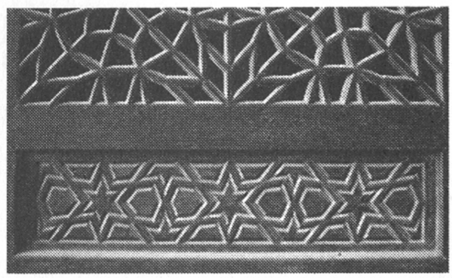

Figure 1

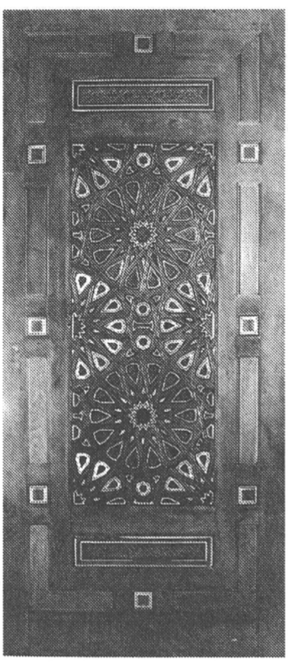

Figure 2

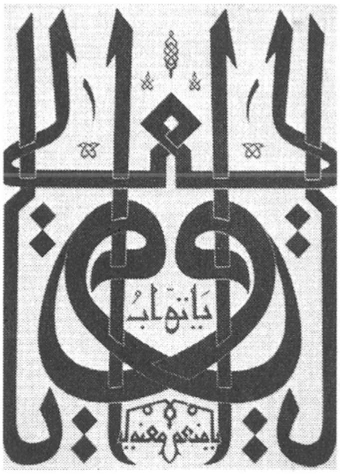

Figure 3

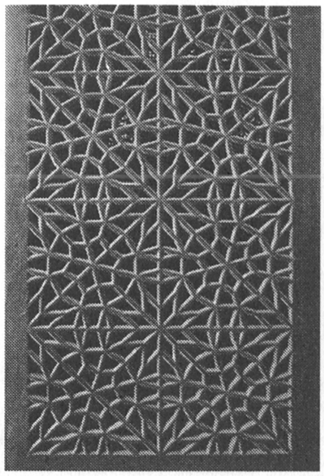

Figure 4

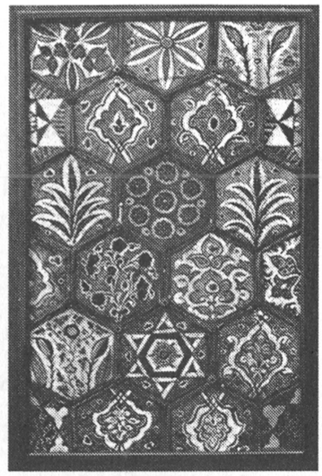

Figure 5

the attention (see fig 5), the same with this other decoration, they are stars with twelve arms regularly repeated, see fig 6). On this tiling, you can see the design of a very colourful network of simple forms which are repeated in linear fashion (see fig 7). You can see it is a “two dimensional network” In figure 8, the network is more complex, it extends to three dimensions in space and volume. It can belong to, as here, a monumental gate, a vaulted hall, or the domes that seem to reach the sky. These pendants of stalactites convex or concave, more decorative than structural, are called “muqarnas” (a type of corbel). The geometric patterns also appear on carpets and all forms of Islamic art, at which point the less attentive observer is tempted to characterise them as triangles, squares, pentagons, heptagons, octagons, dodecagons etc., by the tangled mass of these “simple” figures, their interlacing is known as “arabesque”.

With the first construction of the mosques (the Rocher dome in Jerusalem -692-, the mosque of Omayyads at Damascus-714) the floral representations appear, derivatives of Byzantine art, as our Roman art forms were also derived. They are enriched by the use of decorative symmetrical patterns, tiling plans. With the development of towns, this systematic use of symmetry migrated into civil architecture, thanks to the virtuosity of the local craftsmen – Greeks, Syrians, Copts-, who adapt their techniques to the exigencies of their new masters. About the X and XI centuries, the different trades of the artisans and the Islamic artists allow a dynamic expansion of this art in the mosques, palaces, major colleges, libraries, hospitals, caravanserai, wash-houses, as far as their particular interiors are concerned. Islamic art has therefore found its own particular trait, which extended around the empire, to India and Andalusia. It has a remarkable unity that overrides regional variations. Some see in the hegemony of the recourse to geometry in the art the prohibition made by the Muslim religion to represent the human form. But this is frequently met in the east of the empire without the significance of the geometric pattern being contested. Can a glance of the eye detect that the symmetry is often slightly transgressed in Iran – to represent life – whilst it is strongly held in the west.

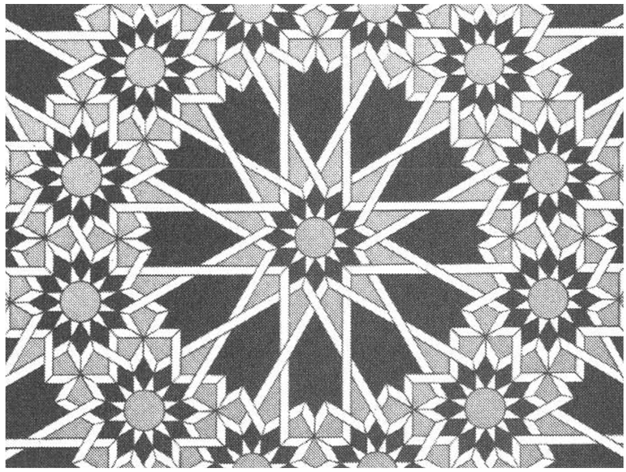

Figure 6

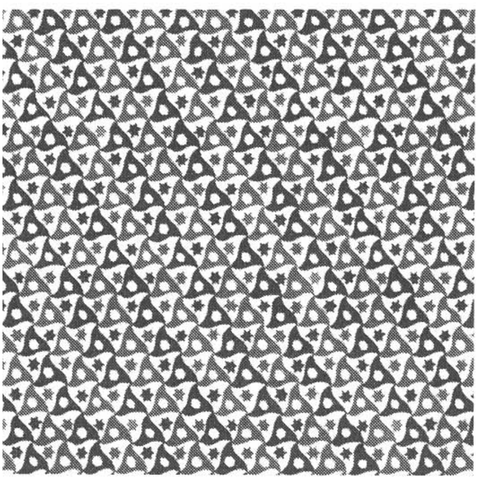

Figure 7

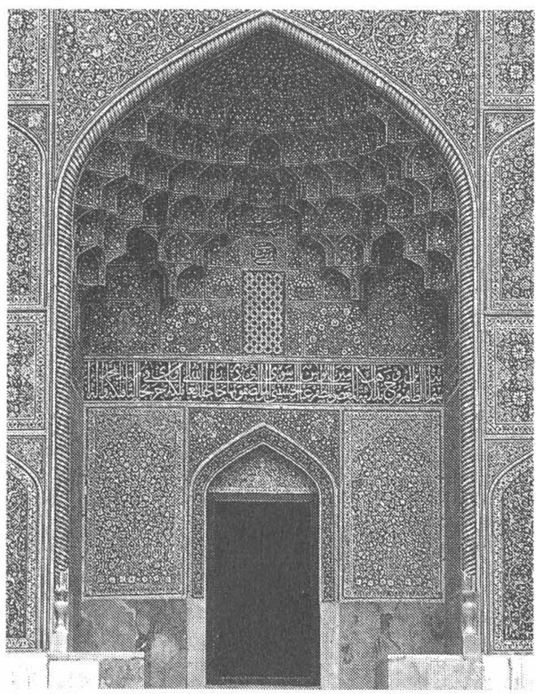

Figure 8

Symmetry and art in the land of Islam

What are the characteristics of this liaison between geometric symmetry and this abstract art that uses geometry so much? The description that I made at the beginning of this article about the freezes, door-panels, tiling and muqarnas refers to an analysis of completed works. I can call together the transformation elements that science has been able to abstract during the course of its history: the translations, rotations, inversions in relation to a mirror. This means that the *posteriori* have nothing to do with the practice of the artists and artisans, as the authors of their works. These issue a sort of challenge to cover a space. For this, they use a geometric pattern that they repeat. All the proportions used are determined by the surface to be filled and by the necessity to repeat. Ideally, they can be made “ad infinitum.” There is therefore a realisation of it that we can call a “periodic network”. But the manner to fill the space is simple if you repeat any of the parallelepipedals, rectangles, heptagons, octagons, or. . . whatever. You must therefore relay the chosen figure (e.g. Solomon’s seal) by other patterns constructed in a fashion to respect the symmetry and to assure the continuity of the trait. All the art of the puzzle is there. It comprises of numerous variations in the function of the introduced symmetry, and of the colours selected. Artists in Islamic countries always use a minimum of different forms, in a well thought out economy of action, in order to make a variation to the unity. The declination or range of the possibilities thanks to the virtuosity acquired leads to agreeable and surprising results, which are to be admired.

Islamic art is a collective art – never a signed work – which unifies the particular achievements of numerous artisans in the work as a whole. The decorators, pavers, cabinetmakers, tilers, etc., are not led by a clerk of the works who imposes a work program on them but each one contributes to the completion of the work. for this, they could work traditionally but also were allowed to invent new variations which enriched the common repertoire. A pattern that is apparently repeated, declined on all the supports, in all techniques. It is not until much later, and from outside this group of artists and artisans, that a great Persian mathematician who died in 1429, al-Kâshî, dedicates a chapter of his famous book "the key to calculation" for decorative geometry and the processes for the construction and ornamentation of doors, windows, walls, domes. They did not imagine that the architects instruct the mathematicians and the geometrists to act together. This results in harmony for the practises, which ultimately, were described and abstracted by the mathematicians.

It is almost the same phenomenon that occurred in Greece; the practise of land-surveying gave birth to the factorization of complex figures in the composition of simple figures, then the study of these figures for themselves and by themselves, without having recourse to whatever attribute. This idealisation of figures (triangles, squares etc.) and the study of their properties mark the birth of the subject, which we now call geometry, just as the practice of counting gave birth to arithmetic and as the study of the equilibrium of balance by Archimedes allows us to leave the curse of the concrete of the plateaux to generalise on the notions of equality, inequality, levers etc., that is to say to leave the study of shapes to come to the tool of reasoning.

Technical thinking and scientific thinking

In this sense, Islamic art presents our eyes with what we should never forget: our knowledge is the result of the long quest made by the human spirit, which is nourished on carrying out its abstraction. The techniques are the first in human history. They progress due to observations, tests, errors, successes, improvements in tools, analysis of practices. This form of rationality is centred on the project in hand, on the tools to be used to attain the required goal. Scientific rationality is another thing. This came much later and paved the way for theoretic construction. The thinkers who were broached for this task saw, for example, the study to be taken of the structures in order to gain an economy of thought, wanting also to study the man, his actions, and sensations, to learn how our thought functions. They relied on these realisations which presented them resemblances to describe them in a homogenous fashion, then opening up for themselves logic, which was also discovered. Science in Islamic countries was the first – by the invention of the experimental method – to place logical research under the control of experience.

The experimental method: another way to bring technical thought to dialectic thought

In the west, since the Renaissance, modern science is enriched by its technical rationality as this is enriched by theoretical thought; the two approaches are necessary and indispensable. The examples do not lack – the measurement of time by solar spheres, then by watches with arms, before the discovery of the laws of the pendulum allow the production of balance type time-pieces; heated machines, discovered by genius technicians, before the study of their shortcomings gave birth to thermodynamics. . .

But to come back to the history of Islamic art. It lay there, witness the splendour of the civilisation that had seen its birth, whilst the western mathematicians of the XIX century wanted, following Evariste Galois, to think about the structures of mathematics. In the same era, the crystallographers put forward the problem of repeating in a space a system of points (which could be compared to atoms). Around the 1870's, the two scientific categories, physics and mathematics, independently of one another, came to establish that there was only seventeen ways to tile this area. They demonstrated that there were only seventeen types of network plans. At the start of the XX century, you noticed that all these networks were linked to the sole Alhambra of Grenada, dating from the XIV century. The news created a sensation and incited the most recent theoretic science to refer to the conclusions of Islamic art. This interest was reinforced a half century later, whilst developing materials in physics referring to the first practical applications of symmetrical groups, in order to interpret the studies carried out in X rays. In the actual state of our knowledge, no savant in Islamic countries had sought to number the group plans, but the artisans had wanted to bring in a work to list the greatest diversity possible in order to find a unity, having proved an inventive enriched proof. . . In 1981, a group of scientists meeting for the study of X rays of the “forbidden” network type by normal tiling, that is to say presenting pentagonal symmetry. The persistence of analogue experiments brought about to conceive the “quasi periodic network”, that posses the “quasi crystals”, passionate research subjects and actual discoveries. The study a *posteriori* of this discovery comes to reveal that these symmetries are present in the decorative Islamic patterns, in the muqarnas projections as well. They have also been described by artists such as Dűrer (see fig 9) or by the scientific technicians such as Simon Stevin. A modest lesson in relation to the anonymous artisans who worked to develop art in Islamic countries and a mark of total interest that could draw the most up to date science in the study of other fields of thought and human practices.

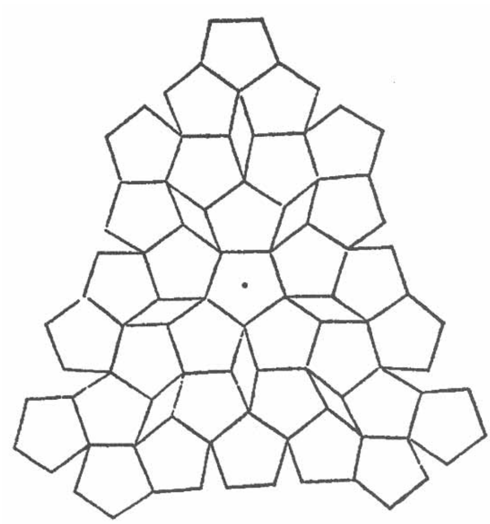

Figure 9

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When the zelliges enter the class. . .
A study of symmetry

Introduction

Artisans of Islamic countries use the properties of mathematics and art in rotation, for the symmetry of tiling, that is to say, of the covering by a patterned plan for the creation of a geometric representation. They embellish numerous architectural works (houses, palaces, mosques, hospitals, madrasa [educational establishments], mausoleums) and decorate different types of books (religious, literary, and even scientific). For example, they replace circles and polygonal figures made with the ruler and compass, an area plan. For this, they use small squares of fired clay most of the time covered in enamel called “zelliges”. These are the same squares that were brought to Nabil and Fadilla to restore a part of their house wall. These became characteristic of the Moroccan-Andalusian architecture. Their presence is noted from the start of the XIIth century with the minarets of Koutoubia and the Marrakech Kasbah. As is shown in the animation film, they are found in the decoration of several rooms in the Alhambra in Granada, whose construction date was in the first half of the XIVth century. They were made in three dimensional patterns called “muqarnas”, as constitutive architectural elements of a vault / archway, as decorations. They are made with triangles, squares and rhomboids. In the XVth century, the Iranian mathematician al-Kâshî, died 1429, was interested in the scientific manner of these muqarnas in dedicating an entire chapter of his *Miftâh al-hisâb) [the key to calculation]* to their construction and measurements.

The richness of geometry presented in the Islamic decorations often makes it a difficult approach. This is represented by the very elaborate figures. The construction of these decorations lies mainly on four transformations of the plan: axial and central symmetry, the translation and rotation.

These four transformations, perceptible by simple observation, integrate learning from school and college. Here, our project is to discover the characteristics of the axial symmetry throughout its artistic works in Islamic countries. In effect, this transformation is only for the program of year 3 and the sixth. The proposed activities could also be the subject of a liaison between school and college.

The axial symmetry, also called "orthogonal symmetry", from the axis d is a punctual transformation such as if M' is the image of M in relation to d, then d is the mediarix of [MM'], that is to say the right perpendicular at [MM'] and passing by its middle. The right d is then a sum of the fixed points: each of its points is own image.

Before describing the activities in detail, we want to present the knowledge and the explicit competences stated by the official instructions for year 3 work here. Also the transverse objectives already described in the introduction of this piece, the activities that we propose following the completion of several of the notional objectives are:

— To understand and know how to use the specific vocabulary: aligned points, middle of a segment, perpendicular properties, parallels' properties, symmetrical figures of a figure given in relation to a right, symmetrical axis; to know how to effect the constructions and corresponding traces;
— To use the instruments (ruler and compass);
— To perceive that a figure possesses one or several symmetrical axis and to verify it using different techniques (folding, calculation);
— To complete a figure by axial symmetry using techniques such as folding and paper calculation;
— To recognise in a perceptive manner a figure blueprint, give its name;
— Show a complex figure in simple figures.

To discover symmetry

It is in the classes of year 3 that a geometric transformation-axial symmetry-will be taught for the first time. Beforehand you recognised the characteristic elements as well as the principle geometric properties (conservation of lengths, areas, etc.)

A general introduction can be made from text book research. The teacher divides the class into several groups that work separately on a place or a building (historic or contemporary). You can consider, for example, in Spain, the Granada Alhambra Palace, or, in Morocco, the mosque Hasan II in Casablanca, the mosque al-Qarawiyine de Fes or even the mausoleum of Moulay Ismaïl de Meknes; several are stated later on. The pupils have to unravel one of the common points of all the places: the presence of rich geometric examples, characteristic of Islamic countries and used as decoration.

The observation should be the point of leaving the apprenticeship. As shown in the animated film, and the children's text, which allows amongst other things, to reach a geometric pattern, which is repeated and its axial symmetry.

This mosaic (see fig 1) is a replica of decorations made from zelliges. Reproduced on transparent paper, it is put on an overhead projector in class.

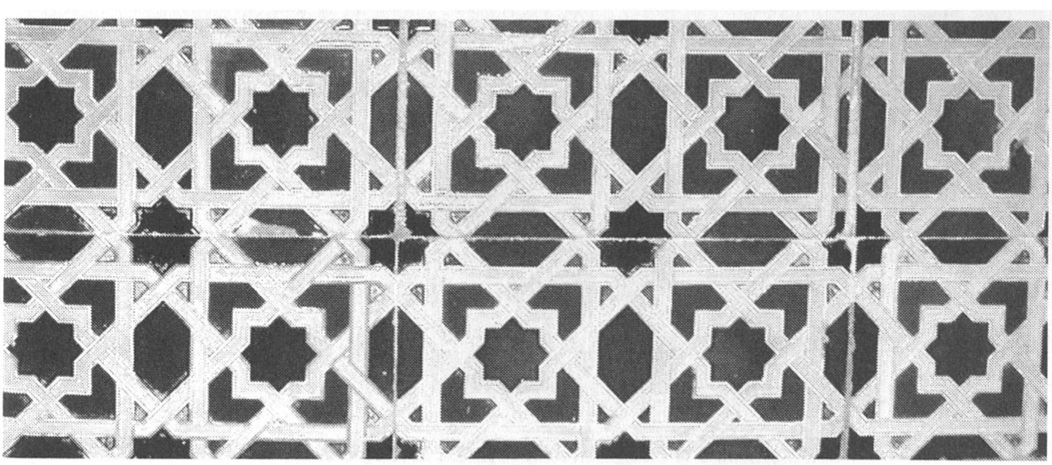


Figure 1: Mosaic of a patio from a modern construction in Granada (XX c.)

For the first time, start a discussion on the description of a piece which, when repeated several times, will let you reconstruct a known mosaic pattern. All the pupils are not going to come up with the same piece; a debate in class is envisaged. Secondly, get the pupils to describe the diverse movements of a constitutive piece (for example see figures 2 &3) which lets them construct it fully. The teacher could then handle the piece as directed step by step by the pupils. You would have to have had sufficient pieces of the chosen piece. Beware of the turnovers that the pupils have to display!

For classes that have the use of a video projector, the teacher can use the software Word or Paint, to envisage the horizontal and vertical movements of the mosaic on screen. For continuity, the animation of the project site can be visualised as a check-up of the activity. This animated film can give rise to the opportunity to ask the pupils to write an essay defining symmetry.

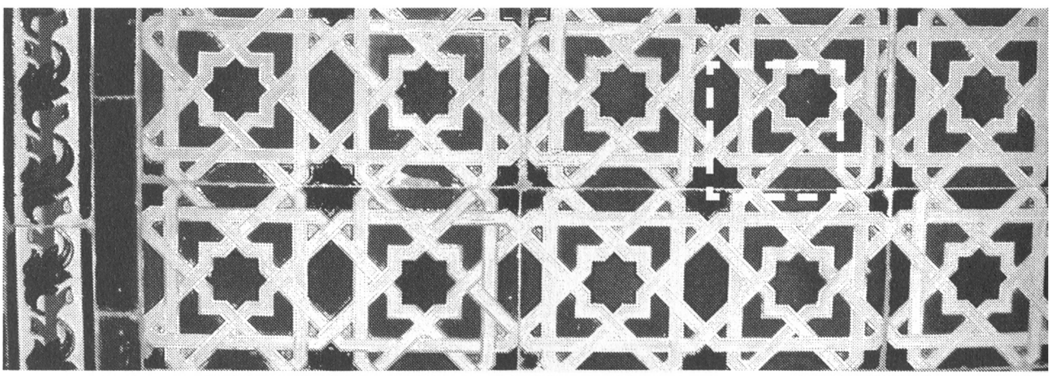


Figure 2: Detail of a piece forming a mosaic

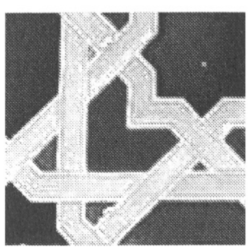


Figure 3: Enlargement of a piece forming a mosaic in Granada

The teacher could follow this by distributing to the pupils the frieze, that they can fold and cut out as they wish in order to determine the constitutive piece of the mosaic as small as possible: the minimum piece. The pupils could be divided into groups to facilitate the exchange of ideas and for handling. They ought to start from their references vertical and horizontal: to draw an oblique axis of symmetry. In effect, more vertical and horizontal axis which correspond to successive folds, it is necessary to take account of the diagonal of the square of the worked piece. A new debate (or a written piece) could be brought about by the pupils giving their reasons why it is certain that the triangle rectangle so obtained corresponds to the minimal piece. For one thing it allows the construction of the entire mosaic, and also it is the smallest for if it does not possess the axis of symmetry, it cannot therefore be reduced. A second question can be asked, the cutting out of the square according to its other diagonal would it have formed a new minimal piece? In conclusion, it is important that the pupils reach an axis of symmetry, that is to say the rule according to which it has to be folded, perhaps vertical, horizontal or diagonal. This axis can, for example, be shown as an animation. In practice, it would be interesting to consider a diagonal axis that is not at 45º to the horizontal.

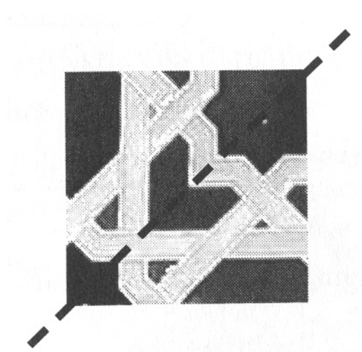


Figure 4 : Minimal piece

Following on, we suggest several activities, independent of the others, which let the pupils to progressively learn the concept of mathematics in the axial symmetry. This realization is fairly difficult for them to understand and not all of them will be able to recognise it.

The transferred (traced) star

The goal is to construct, in two different ways, a first star, that will have as its base the following activity: a frieze of stars. This construction allows the first identification between folding and axis of symmetry.

For the first time, the full traits of the figure 5a are to be reproduced on tracing paper. The pupil should fold along the dotted lines in order to reproduce the figure in the three remaining quarters. The result is in figure 5b. Secondly, the teacher takes care to reproduce the figure 5a on white paper and the pupil ought to complete it without using the tracing paper. It is necessary to choose a paper of sufficient thickness, so that the pupil cannot see through it. Also, you have to put into force a procedure to replace the reproduction by tracing and by folding. Nevertheless, one can fold the leaf again to check the figure.

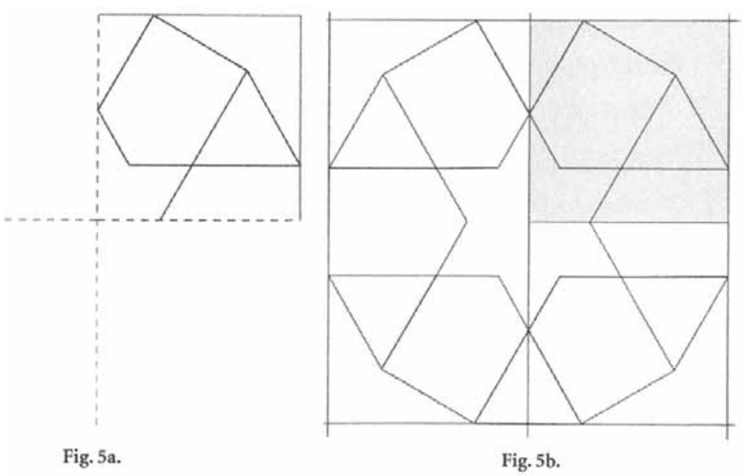


Figure 5 : The traced star

The frieze of stars

This second activity suggests the construction of a frieze of which the central element is a star with six arms previously made.

The first work on this frieze is purely geometric: it consists of extending the frieze, of which the first two elements have been made. For this, the pupil is left free to carry out the project from the start. Following.

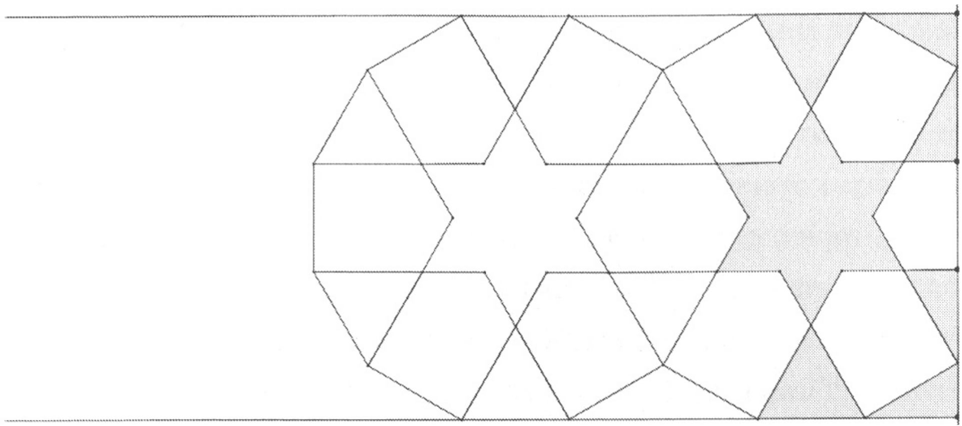


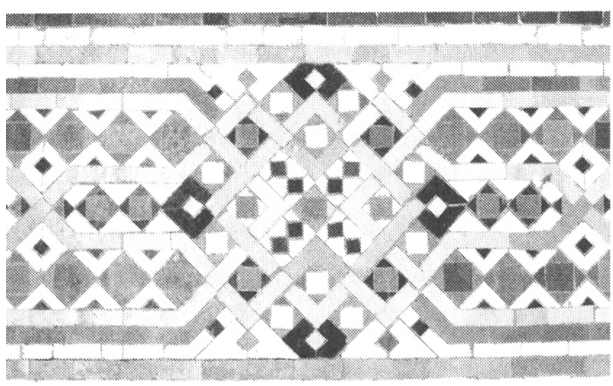
Figure 6 : The frieze of stars

its construction, the teacher encourages a debate in class on the different ways of doing it. Certainly all the pupils should be able to make the axis of symmetry with a straight line.

The essential point is to understand that the fundamental principle of a frieze lies in the repetition of its figures, possible repetition by folding or by . . . axial symmetry.

The introduction of colour

The frieze can, first of all, be coloured by a single colour, as in figure 6. This is an opportunity to study the way of colouring the frieze so as not to "lose" the symmetry. The pupil should bring together all the previous results on the idea of axial symmetry, whilst mentally folding it. But, the second time, with the introduction of a variation of colours, the star frieze is also the occasion for a numerical digression.



Detail of a modern frieze from the great mosque of Hassan II at Casablanca (XXth century)

The teacher defines a pattern of n *(n > 2)* colours. The aim is to determine the colour

of the *p*-star. It is interesting to progressively increase the rank of *p* (that is to say, its position in the frieze, to know the *p* star) the star that you want to know the colour of. for a sufficiently small rank of *p*, that is to say corresponding to a star represented on the frieze, the pupil simple looks for the desired colour, But, for a relevantly large *p* (with no majorant), you have to use a different strategy:
— if $n = 2$, the research leads the pupil to identify the colour of a star with parity or imparity to its rank;
— if $n > 2$, the pupil has to call for an interpretation of the rest of the Euclidian division of p by n.

For example, the teacher defines a given sequence of $n = 3$ colours: blue, orange, green; and gives the pupils a number *p* to know the colour in principle of the star ranked *p*. The research ought to be progressive, *p* ought to take greater and greater values.

Let us take some examples with p being sufficiently big for starting the pupil to describe:

— if $p = 158$. the Euclidian division of 158 by 3 gives the connotation: 158 = 3 x 52 + 2. The interpretation of this lets us describe the frieze: there will be 2 series of three colours and two supplementary stars, these two stars will be, in order, blue and orange. In conclusion, the 158th star will be orange;

— if *p* = 241. Then 241 = 3 x 80 + 1. The frieze will be made with 80 series of three colours, and the 241st star will therefore be blue;

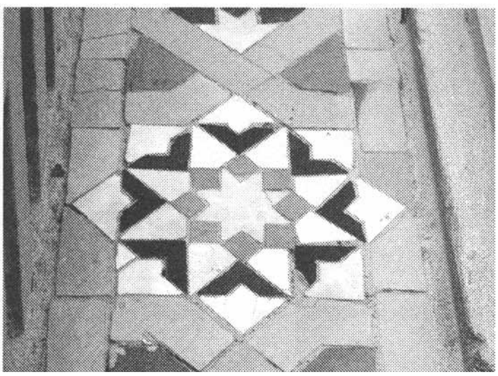
— if *p* = 345. Then the remainder of the Euclidian division is 0 for 345 = 3 x 115. The 345th star will therefore be green.

These three examples suffice to describe all cases in reply to an Euclidian division by 3 as is possible: 0, 1, 2.

The teacher can then give a new value for n more important and, again, a different value for p. this numeric research is good for a written exercise. It could also be done in the sphere of a research story. The pupil ought to also recount and explain his thought process, which, in this sphere, is experimental, and include his experiences at school and his theoretical knowledge. This can be used as a revision, of his introduction to Euclidian division.

The eight armed star : two intersected squares

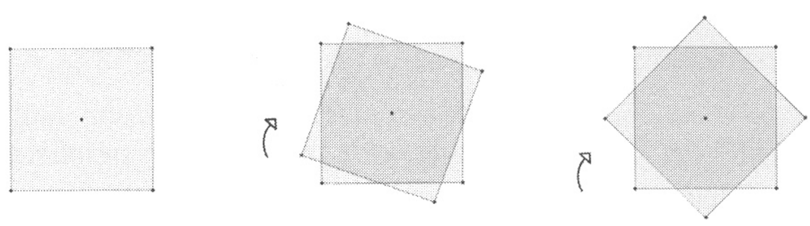
A contemporary of Louis XIV, Moulay Ismail (1645-1727) became Sultan of Morocco in 1672. Qt the beginning of his reign, he chose Meknès as the capital of his kingdom. His mausoleum, that is the place where his body lies, is a mosque in this town, constructed in 1703. Where you can find some very beautiful mosaics, on the basis of the eight armed star. Here are two examples which could be the starting point of a new formation of the eight armed star, and have for their basis the eight points. The teacher can emphasis this by asking them to write about the construction, and trying to reconstruct them.



Showing the details of the design in the Moulay Ismail mausoleum at Meknès (XVIII century)

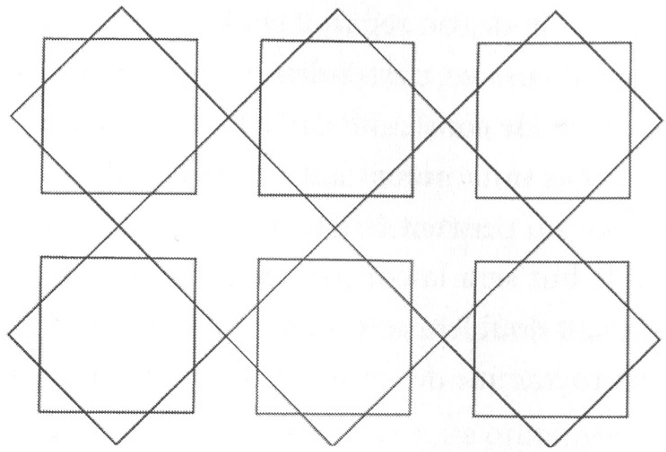
Patio fountain at the Moulay Ismail mausoleum at Meknès (XVIII century)

In the pupils' explanatory texts, the teacher can show the design by superimposing two squares. One should be a quarter turn on top of the other, based on their centres. This is a chance to explain a new geometrical transformation: rotation. This is not on the school curriculum, but it can be useful to show the axial symmetry is not the only geometrical symmetry process available.



Rotation of the square around its centre

One of the mosaic patterns most often used is this star with the crossed stars as seen:



Crossed mosaic of
stars with eight arms

The star with eight arms is ideal to learn the notion of the axis of symmetry by folding / cutting out. In effect, the pupil equipped with a file of paper squares and a pair of scissors, ought to make a star with eight arms using the least amount of cuts possible. The pupil ought to find the minimal element (see figure 7a) making the structure of the normal pattern (see figure 7b), that is;

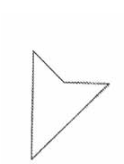


Figure 7a : base element of the star
with eight arms

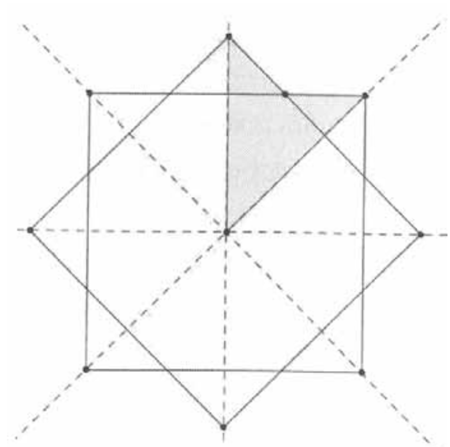
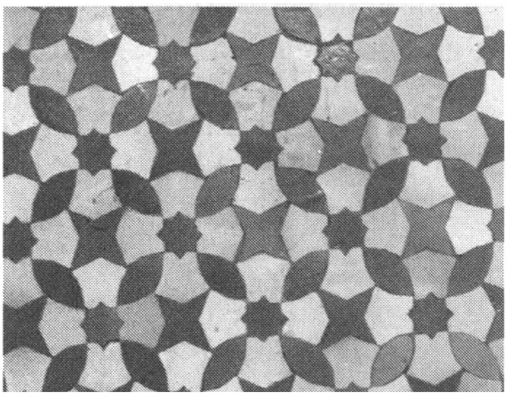


Figure 7b : star with eight arms and
axis of symmetry

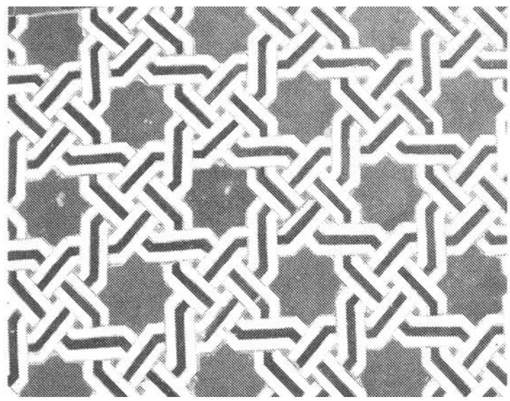
The pupil should arrive at the result of three successive folds : two folds parallel to the sides and a diagonal fold for example.

Make a tiling by envelope
a collaborative project

This fourth activity allows the pupil to "tile the plan", that is to say to fill a two dimensional space (perhaps a piece of paper, a wall of the classroom etc.) without leaving any space empty. The tiling is a process of decoration well used in Islamic art, of which these are some illustrations. They can be shown, as an example to the pupils by making a transparency copy for a projector. They are both comprised of the star with eight arms, that we have just mentioned.



Tiling from the mausoleum of Moulay Ismaïl at Meknès (XVIIIth century)



Tiling of a pew at Hassan II mosque at Casablanca (XXth century)

This activity is about the properties of the parallelogram, which tile the plan whatever their dimensions or shapes (parallelograms, rectangles, squares, or diamonds). We will take for our base shape a rectangle that we will "transfer" by successive symmetry.

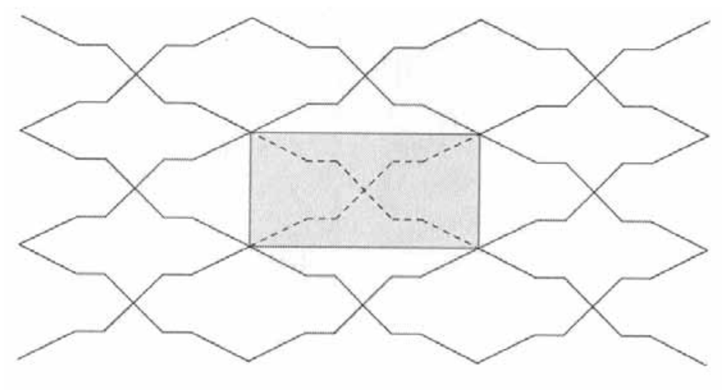
Each pupil constructs an element of tilage, and the teacher assembles it as a whole. It is important to forewarn the pupils of this objective, so that they know that the overall success of the project lies in their collective actions. Precision tracing and cutting is required.

The aim of the exercise is a rectangular envelope of any form and self-adhesive preference.

From the start, the pupil draws dotted lines on the back of the envelope following the following plan:

— trace the diagonals on the envelop;
— place the middle of the four halves of the diagonals;
— retie the middles two by two in length;
— place the quarter and the three quarters of each of the segments obtained;
— retie, two by two, diagonally, the obtained points. These two segments cut the centre of the rectangle.

Then, cut along the length of the dotted lines of the envelope. Finally, process the pieces laterally to obtain the base element for tiling. It is now time for the teacher and the pupils to assemble all the elements. . .This work could be produced from envelopes of different colours to show off the tiling better.



Tiling by envelope

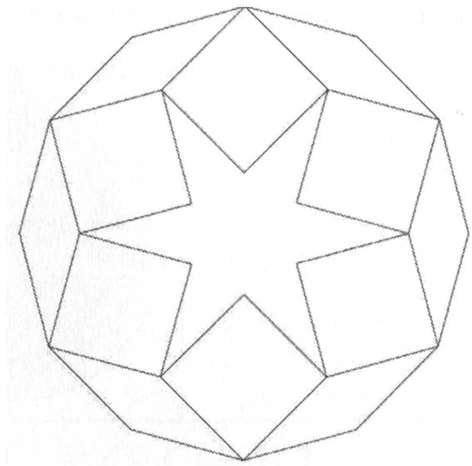
Axial symmetry: constructions

The dodecagon can be made in several ways. One of the easiest is without doubt that obtained by making three squares inserted in a base circle. This last activity pans out in four separate independent stages one after the other. We know, once again, that it is a difficult activity that ought to be reserved for pupils, who have completely understood the previous activities.

First stage : axis of symmetry

The pupil should begin by identifying the above figure’s axis of symmetry and colouring it in a manner to conserve all its axis. The teacher will state the maximum number of colours to be used.

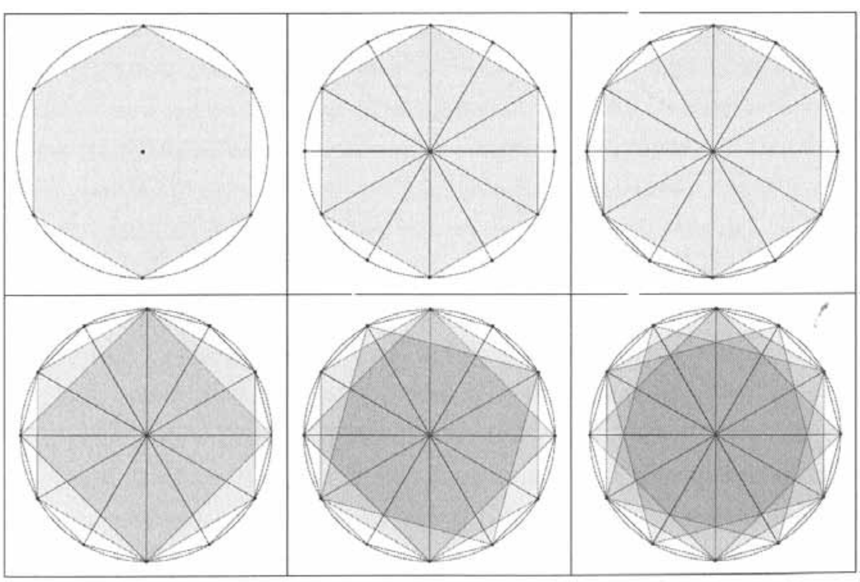
On this occasion, the pupil, will take notice of the poor amount of freedom he has in the choice of colours against the number of axis. In effect, the colour of a zone is governed by the symmetric zone. It is the symmetry that governs the repetition of the colours from the start for each of the individual figures (diamond, square, star arm).



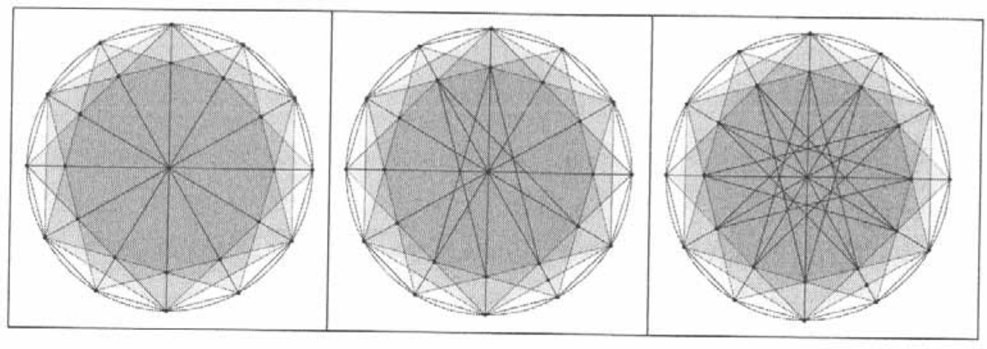
The dodecagon star

Finally, the construction of the figure. A construction risk program is tedious for the pupil to follow, and does not present any particular interest. The pupil is encouraged to follow the below "drawing band" so that reasoned observation will let him see the final construction. The teacher could ask the pupil to write down, bit by bit, the realised tasks with the appropriate vocabulary (circle, centre, hexagon, diameter, middle, square, etc.)

Second stage : overlapping of the squares



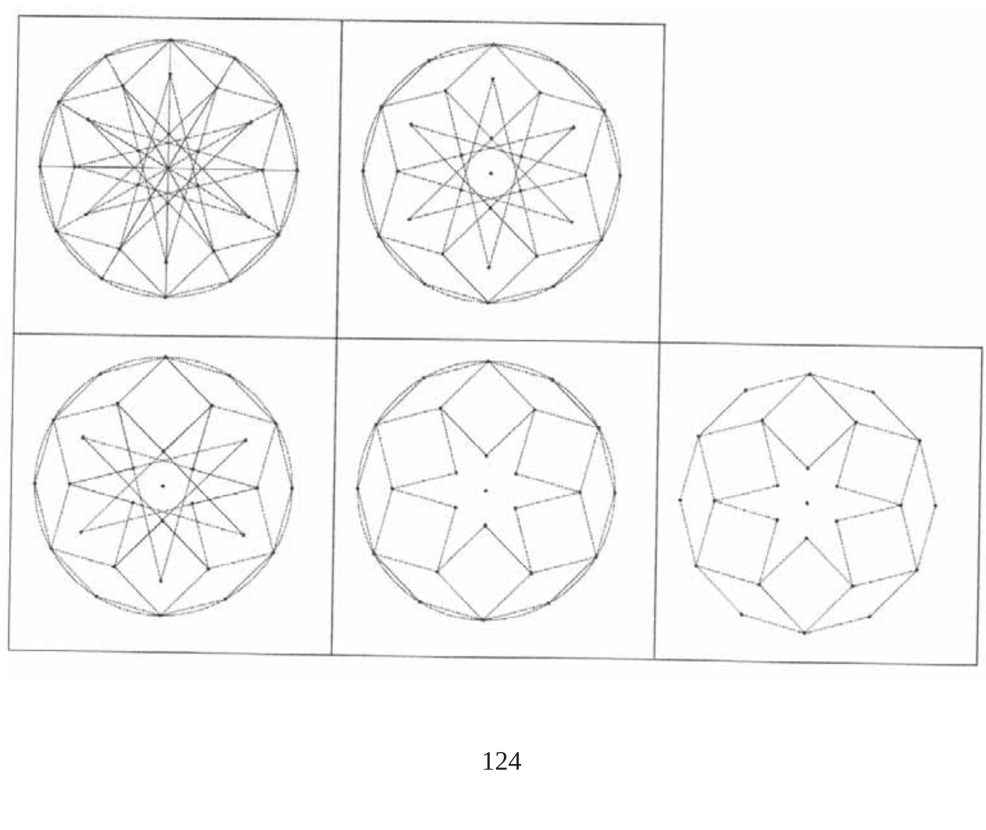
Third stage : central star with twelve arms



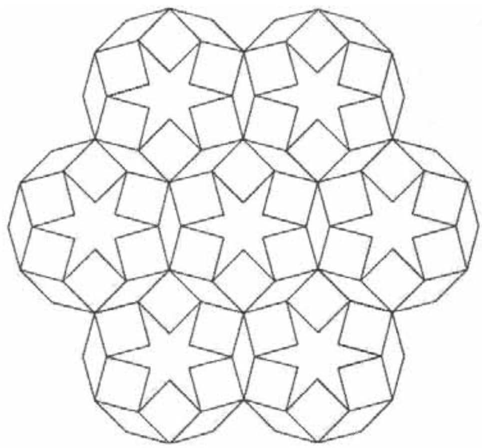
Note: it is possible to keep the star with twelve arms for the final tiling, but it is evident that the mark will be less pronounced.

Fourth stage : elaboration of the final pattern

This stage is the most difficult from the observational point of view and in the construction since it may be necessary to start again. But, there again, that is symmetry which is a work. . .



Lastly, the teacher produces the following tiling, in the form of an A3 poster, to be displayed to the pupils, suggesting that they copy it sharing their own models.



Repetition of the dodecagon by symmetry

Conclusion

These activities have a dual purpose. First of all, they let us discover, define and construct the symmetry in class. Then, they run alongside the cultural development of the pupils while letting them have the opportunity to discover the civilisation in their art.

At all times, the activities can help to show the child where he is going wrong. In effect, they allow them to understand that the symmetry is not only a conscious human construction and reflection constructed only to be good looking. To conclude our study in symmetry, it is indispensable to observe some of the “natural” handiwork that has been made.

The crystallography describes the structures and properties of the crystals from the analysis of their symmetry. The ice crystals probably provide the most common examples for the pupils: the snowflakes. All different, they nevertheless are all constructed from the same hexagonal structure. A series of photographs of the snow crystals could be, for example, the basis for an evaluation on the axis of symmetry.

Human beings (flora and fauna) can also be the subject for observation. Flowers, butterflies, shellfish, cells of honey, etc. are all natural evidence of symmetry that the pupils have no doubt already come across.

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The favourite game of Nabil and his sister Fadila was to resolve the enigmas which occurred when they were observing what happened around them, or in them. They were more passionate about this, than others of their time were, a little magic was about them, like the day when they wanted to understand the secret of the astonishing decorations on the walls of their house. . .

That day, they were so hot that Nabil and Fadila stayed at home. They were dozing outside in the shade, sweetly interrupted by the gurgling of the fountain that was in their inner courtyard. This rest was of a short duration for they were soon disturbed by the workers who had come to repair the wall against which they had installed themselves. The men put piles of ceramic squares on the ground and recommended they did not touch them while they were away. That meant nothing to Nabil and Fadila, now well awake, and pricked with curiosity. Being alone, they eyed each other mischievously. Nabil stood up to see the design of the part of the wall that was still intact, whilst Fadila, on the ground, started to stack up the squares.

— Nabil, look, if I take a square from each of the two piles, I can see which is the right one in inverse relation to the one on the left. . .like my hands!

And she looked at her hands stretched out in front of her and she touched her left thumb with her right thumb. Then she separated them, palms turned towards her, the right little finger touching the left one. All excited, she began associating the squares two by two, then she stopped, perplexed. In spite of the contortions that she made with her hands, she didn't know how to continue.

During this time, Nabil let his eyes meander on the decorations on the wall, in an absorbed sort of manner. He whispered to his sister:

— Stop annoying me! I am trying to understand how you make designs as complicated as this with little squares!

— Shhh, help me quick to arrange them, the men are coming back!

They put the squares back into piles, precariously. One of the workmen asked them:

— Here, here, you can see the squares have been disturbed! Have you touched them?

Nabil and Fadila opened their wide, innocent eyes. The man changed his tone and smiled:

— OK, you are curious how we work?

A smile lit up the faces of the children, They sat down in a corner and watched. The way Fadila had done was good, but the workmen used several types of squares to get to the large designs on the walls, and the spectacle was fascinating. Each one worked on his side, but they were all working in harmony on the monumental decoration. The designs repeated themselves, you could not see where they had started and where they had finished.

After a moment, Nabil frowned his eyebrows and murmured to his sister:

— How does each one know what to do? The designs repeat, but how do they know the start? And then. . .

They were interrupted by a man who had come into the courtyard, he presented himself simply:

— Hello, I am called al-Kâshî, and your questions, I've asked them myself! If you like geometry, you can find the answer to what the workmen do automatically. What you like me to tell you about it here? Come, we shall sit in front of this beautiful wall. Watch. . .

What happened next is lost to us, it was a long time ago, the memory is lost! It only remains to say that the workmen, were the first to use the secrets of symmetry, before some savants such as al-Kâshî became interested in it, in their turn. And in one way or another, as they had accompanied Nabil and Fadila, they will accompany all of you that ask the same questions, one way or another. . .

The water pump

Al-Jazari's water pump 130
Salim Al-Hasani and Mohammed Abattouy

How to draw up water from a river? 136
The invention of the al-Jazari pump
Cécile de Hosson, with the collaboration of Loïc Chesnais and Joëlle Fourcade

Children's text 146
Anne Fouche

Al-Jazarî's water pump

Arabic mechanics and technology

Three principles dominate mechanics in Arabic tradition : theoretical or static mechanics, the study of hydrostatics and specific gravity, the science of machines, which is a discipline dedicated to the description of machines and the study of how they work. Called in Arabic *'ilm al-hiyal*, which signifies "the science of engineering processes", the science of machine constitutes the forerunner of engineering sciences. It understands the construction and description of machines and the explanation of their applications in different practical tasks: lifting heavy objects, to pump water from rivers and wells, to construct and make work clocks, automations and other ingenious engines.
Some works have been made reference to:
— the *Kitâb al-hiyal (The book of engineering processes)* of Banũ Mũsâ (IXth century) gives the description of a hundred machines of which the majority are sophisticated mechanisms to serve liquids and drinks;

— the *Kitâb al-asrâr fi natâ'ij al-afkâr (the book of secrets about the results of ideas)* of al-Murâdî (IXth century) consists of descriptions of water watches and automations;

— the *Kitâb 'ilm al-sâ'ât wa l-'amal bihâ (book of the science of watches and their use)* of Ibn Ridhwân as-Sâ'âtî (XII century);

— *l'Al-Jâmi'bayna al-'ilm wa l-'amal al nâfi'fi sinâ't al-hiyal (Compendium of the theory and practice in the construction of machines)* of al-Jazarî (XIIth – XIII th century);

— *l'Al-Turuq al-saniya fi'l-âlât al-rũhâniya (methods for pneumatic machines)* of Taqî al-Dîn ibn Ma'rũf (XVI century).

Al-Jazarî : an innovative engineer

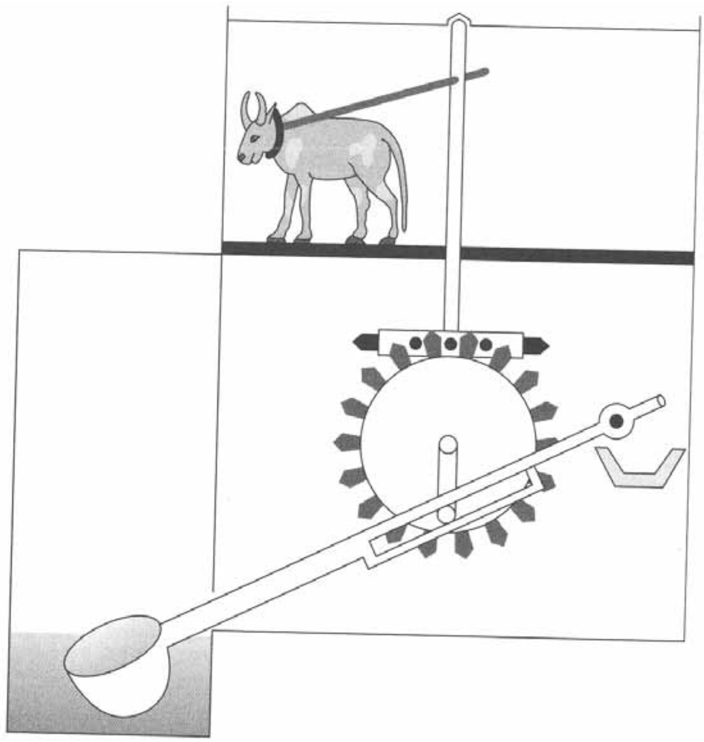
Badî' al-Zamân b. Ismâ'îl al Jazarî is considered as the most famous and innovative of Arabic engineers. He was born in the middle of the XIIth century and he lived in the region of al-Jazîra, situated between the Tigris and the Euphrates. In 1174, he entered into the service of the Princes Banû Artaq who governed the region of Diyarbakir, today in the south of Turkey. At this time, this was a prosperous region, which enjoyed peace and stability. Living at the court of the Princes Artulides and benefitting from favourable work conditions, al-Jazarî rose in grade and ended uP functioning as Ra'is al-a'mâl (chief engineer) of the principality. It was at the behest of the ruling prince that he conducted his great treatise in mechanics, the only one that has been left to posterity. According to all probability, al-Jazarî died in 1206, some months after having completed his work.

The book in question is a monumental work in fifty chapters, which represented some impressive mechanics. These fifty chapters were divided into six categories: ten chapters were dedicated to clocks and clepsydras, ten for receptacles to serve drinks, ten for receptacles and vases for ablutions and bleeding, ten for fountain spouting and intermittent and constant flutes, five for machines to raise water and five to diverse machines.

The work contains such details that show the technological mastery of the author. In fact, this was one of the best engineers of pre-modern times. Also he improved the design of several machines in existence at the time, al- Jazarî fully explained the methods of construction and assembly of fifty machines that he studied in his book.

Mechanism of the water pump

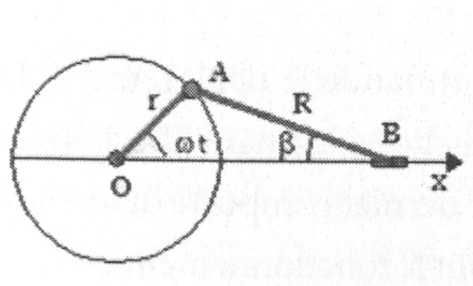
Al-Jazarî dedicated the fifth chapter of his book to machines that rose water, of which two were pumps. The first of these pumps (see the design on the following page) had a fixed crank on a toothed wheel whose circular movement is fed by a stalk moved by an animal installed on a raised platform.



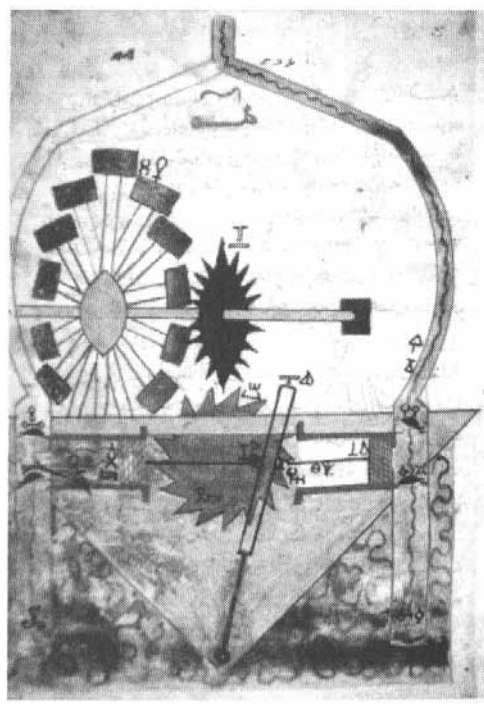
The crankpin of the crank slips over the interior of a practical opening in the sleeve of the ladle, which is fixed at its extremity in a way to not let it spill out to the sides. In turning under the effect of the circular movement of the toothed wheel, the crank makes it displace at the top, then the bottom, the sleeve and the ladle and, by consequence, the scoop of the latter. The scoop is refilled as it passes into the water on its downward pass as it becomes horizontal; the water is poured out by the extremity of its hollow sleeve into an irrigation channel and from there, to the chosen place.

The second of the two al-Jazarî pumps, bore an important technological innovation, fairly significant in the history of technology. It consists of the first complete application of the crank with connecting rod, some three centuries before this technique made its appearance in Europe.

The principle of the crank with connecting rod is: a stalk OA of length r turns around O at the constant speed ώ. A stalk AB allows the transformation of the movement of rotation of A into a rectilinear movement. It is hinged in A and a slippage obliges point B to rest on Ox. This system permits other things, to transform a rotation movement in one alternative transformation movement (to and fro). Several modern machines are based on this simple mechanism in theory but quite complex to put into operation as the jigsaw, sewing machine and piston engines.



The al-Jazarî pump is in fact made out of two pumps, one sucking the other exhaling in an alternate manner. In this double pump (see document below and page 137 also), a water wheel turns a vertical toothed wheel which, in turn, turns a horizontal wheel. The latter making the oscillation of two opposed pistons made out of copper. The cylinders of the pistons are linked with sucking and exhaust pipes which have opening and closing valves, they only open in one direction (upper). The sucking pipes put the water into a ditch, at a lower level and the exhaust pipes discharge it in the irrigation system, situated 12 m beneath the pump installation.



The al-Jazari pump (taken from the manuscript of Ahmet III 3472, Topkapi museum, Istanbul.

The working of this sucking and exhaling pump can be described as follows. The fixed blade wheel at the end of a horizontal beam is powered by running water. In turning, it powers the toothed wheel placed at the other end of the beam. The teeth of which enmesh with the teeth of a crank-pin disc placed at the end of a beam parallel with the first. The fixed crank-pin on the toothed disc forces the deplacement of the sliding beam to the right and left, operating alternatively one and the other pistons in its cylinder. This latter has two valves, one for sucking and the other for exhaling, its operation being carried out by variations in pressure. Each piston is made from two discs placed at the end of a stalk. Between these two discs a linen file is rolled which plays the role of a watertight joint and increases the efficiency of the pump. The piston and the stalk form a solid movement action of translation in relation to the axis of the cylinder.

The two pumps operate in the following manner. The sucking valve of one of the two cylinders being open, the piston, in its movement pulls in a volume of fluids at a constant pressure; after which the sucking valve is closed, compressing the fluid without any change in volume and opening of the exhaust valve. Then, the piston, in its inverse movement, re-pushes the volume of the fluid upwards at a constant pressure. When the cylinder is completely empty, the exhaust valve closes whilst the inlet valve opens to allow the water to be again sucked into the cylinder by the piston.

The to and fro movement of the two pistons is powered by a connecting rod crank system which transforms the continuous circular movement of a crankpin disc in an alternative rectilinear movement of the stalks of the two pistons.

According to the sketch of the figure on page 137, the output of the two pistons and, accordingly, the sucking and exhaling cylinders [inlet and outlet] can be described as follows: On the instigation of piston N, the water is sucked from the river into the cylinder T and put out into the tube F towards the ditch and, from there, to the chosen dispersal point. Reciprocally, on the return of the piston N, the water is drawn into the cylinder S before being put out via the tube Z.

From the innovation of the principle that rules, the ingenuity of its concept, the complexity of the different phases of its operating, the difficulties of the construction of its components, the al-Jazari piston pump is in a prime position in the evolution of technology. In effect, it incorporates an effective means in converting rotational movement into a rectilinear movement thanks to the connecting rod crank. Also, it makes use of the principle of double action and introduces for the first time pipes that can suction liquids. Moreover, our mechanic describes its everyday usage, and does not make a big deal out of it, as he does with his other inventions and his advanced originality at the beginning of his book. This "nonchalance" perhaps indicates that this pump was already in use when it was described by al-Jazari. However, the fact that it was singled out for presentation at the end of his penultimate series of inventions (the last, from the appendix, did not show any new machines) lets us think that he was aware of its value in that such an original invention represented the summit of his craft.

By his innovations, the al-Jazari pump can be considered as the first suction pump. The claim that the Italian engineer Mariano di Jacopo Taccola was the first to describe a drawing up pump has not been proven. It is probable that the appearance of the suction pump in the mechanical treatises of the European Renaissance came from an Islamic source. Until the present time, we do not have any information about the circulation of the al-Jazari treatise in Europe in this era, but it cannot be excluded, at least by virtue of the large amount of works in the Islamic world and the multiple means of exchanging information and the transmission of scientific technology between the two banks of the Mediterranean during medieval times, a communication network for science existed in several disciplines.

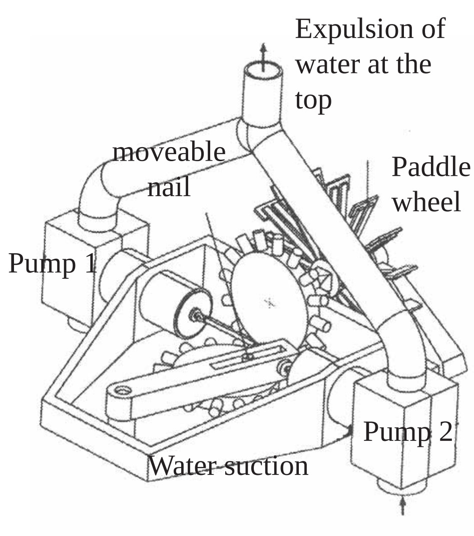


Diagram of the al-Jazari pump

How to draw up water from a river?
The invention of the al-Jazarî pump

Objectives

There are devises allowing the transmission of rotational movement:

Toothed wheels.

The connecting rod crank system allowing the transformation of rotational movement into translated movement.

Reference to the science and technology program for year 3 primary school

“The world constructed by man : transmission of movements”.

Equipment

Dishes, water, supple pipes, plastic T squares for diversion, syringes, Celda© technology kit, wooden beams, cardboard roundels.

It has been a long long time since the human race deployed its powers of thought and invention to fathom out the various ways to get the water necessary to irrigate their fields. The recourse to pumps, especially, allow us year around to draw up water from the rivers. This itself is then transported by canals, sometimes far away from where it was drawn, to different parts to be irrigated. The invention of pumping machines was undertaken in the Middle Ages. They were the fruit of contributions from several Arab speaking savants. It is the one of al-Jazarî that we propose to study with the pupils.

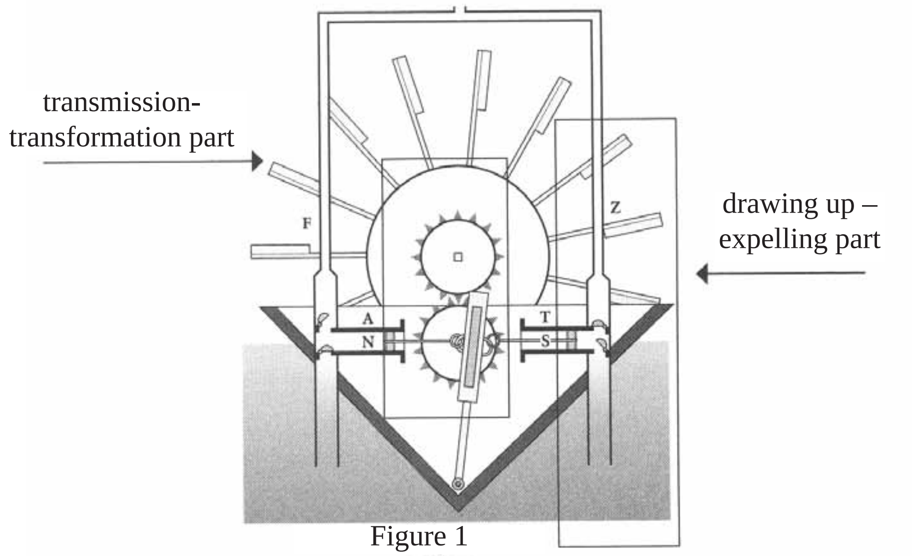


Figure 1

The model presented here is structured around four activities. The first looks at the suitability of the problem for the pupils; “How to draw up water from a river?” The following two parts have the purpose of getting the pupils to discover the specific parts of the pump that we choose to study separately in a way so as to not overload the pupils’ learning curve. The hydrostatic part “drawing up / discharging” will therefore be studied in itself (activity 1, see the following figure), whilst the mechanical part concerns the transmission and the transformation of the movement (activity 2, also see below); the fourth activity having the purpose of associating these two parts, studied separately, whilst understanding the overall mechanics of the pump.

Introductive activity:
Exploitation of the text for children

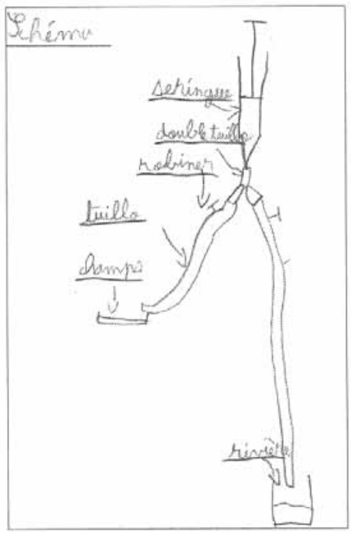
The debut activity: reading of the text by children. The pupils should discover there the problem that they are going to have to solve, the problem about which we are concerned: “Imagine that the savant al-Jazarî could have suggested to Nabil to pour water on his sister Fadilla even when he finds himself higher than the river bank”. In this first phase, that we call “introductive activity”, the role for the text is therefore to introduce the question to the pupils. They are asked to imagine (in an individual manner) a way to draw up water from a river, which would then be able to be used to irrigate fields that are higher up.

The children's text contains a certain number of clues about the roads that the pupils could explore in order to solve the question in hand. The movement of the "winch" Nabil's arms lead onto the road of the bladed wheels: some of the pupils have in their head images of windmills whose wheel is powered by the river current. They understand that will allow the drawing out of the river's water, but they are at pain to conceive the manner in which this water can be gathered before it returns to the river, as it is carried by the movement of the wheel. It is therefore necessary to find a way to "push" the water to the edge of the wheel when it is higher up. We have a discussion here to form a collective result where everyone can express his ideas. The construction of such a machine would need a double reply; first the water needs to be raised, and then pushed on. All this needs to be done without tiring you out.

Activity No. 1 :
Draw the water by suction and expulsion

The children are equipped with basins full of water, taps, a syringe, supple pipes, T squares to divert it. They must find out how to get the water from a basin on the floor to a basin on the table. They notice that it is possible to lift the water by suction but that it is then impossible to re-gather this water into a receptacle. A problem is asked then: how to conserve the water that you succeed in raising to a certain height? This difficulty necessitates imagining a complementary device: to draw up the water, certainly, but you need to have the means to recover it. The pupils share this problem out between them and discuss possible the solutions. The idea of an intermediary reservoir, higher up, is then introduced; it is the water of this reservoir that will then be expelled.

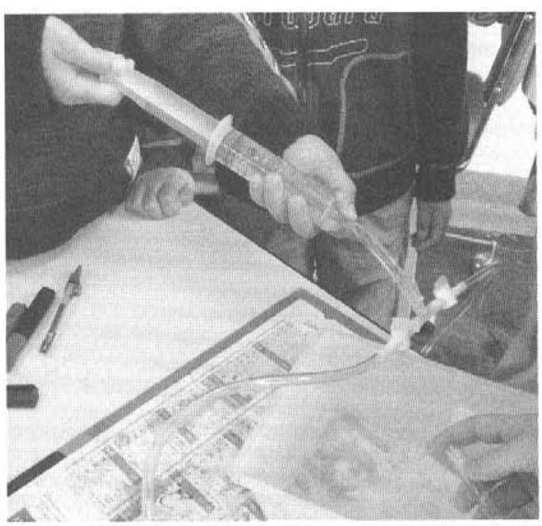
The full device as thought up by the pupils comprise of the following elements: a first pipe on which is placed a tap R^1, a T square on which the syringe is placed, a second pipe with a second tap R^2 placed on it (see following schemas and drawings)

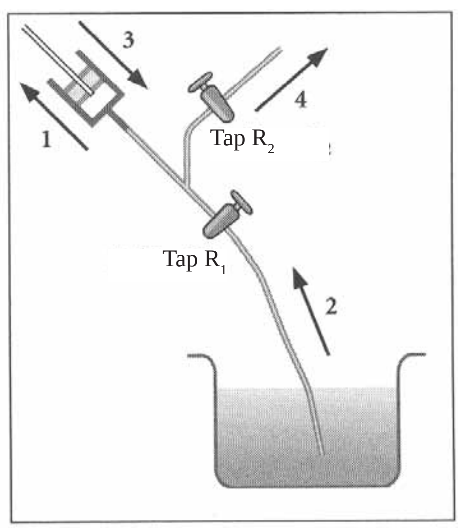


Benjamin's drawing (CE2)

Myriam's drawing(CE2)

The device therefore works in two stages. First, the water is drawn up into the reservoir of the syringe by suction (1 and 2 in the below schema) via a first tube. The tap R^1 is open, R^2 is closed. You close R^1, and open R^2, then you push the piston of the syringe (3) in a way to expel the water to the intended place (4).





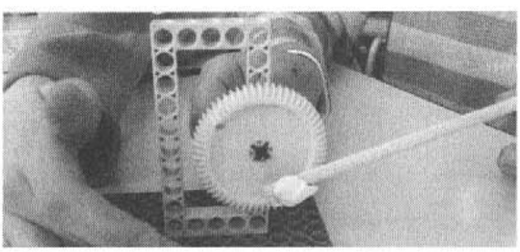
At the end of this activity, the pupils understand that the drawn water depends on the coming and going movement made by the piston of the syringe. We still have to find the means to do this without human intervention.

Activity No.2 :
To transmit and transform a movement

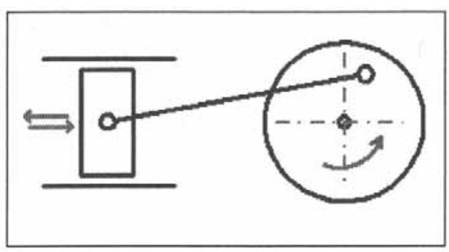
The aim of the preceding activity was to draw up water from a basin. Now, in the children's text, it is a question of water from a river. This is a movement, contrary to the water from a basin, and this movement allows the turning of wheels. This idea did not escape the pupils when they read the children's text. It is carried out in the following sequence.

Stage 1 : Transforming a rotational movement into a to and fro movement

After having reminded the pupils of the problem that was left in suspension at the end of the preceding activity (to find the means of maintaining a coming and going motion of a piston without human help), the teacher comes back to the idea of the paddle wheel as some had suggested. He explained to them that it is possible to use the motion of a wheel to create a coming and going motion. But how to do it? To reply to this question, the children equipped with a wooden beam at the end of which there was a cardboard roundel adapted to the reservoir section of the syringe; this beam replaces the piston, which was too difficult to insert in the syringe's reservoir. They also had a toothed wheel and some glue. This stage needs a little research which the master determines. The idea of motion having been researched, it is necessary to fix the beam on the wheel itself (see figure below on left). They will discover through the system "connecting rod crank" (see figure below right).



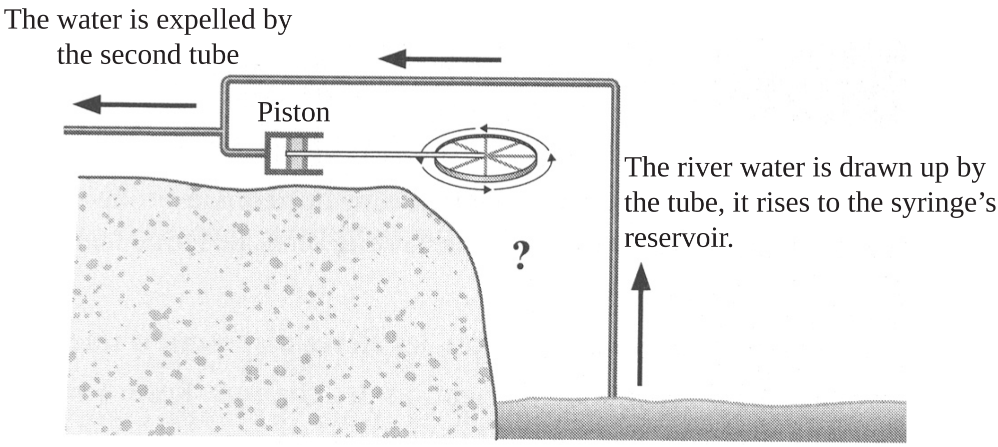
The coming and going movement of the wooden beam connecting is obtained by a connecting rod crank; in turning the wheel (rotation), the beam is moved forwards and backwards (translation)



Drawing of the rod system

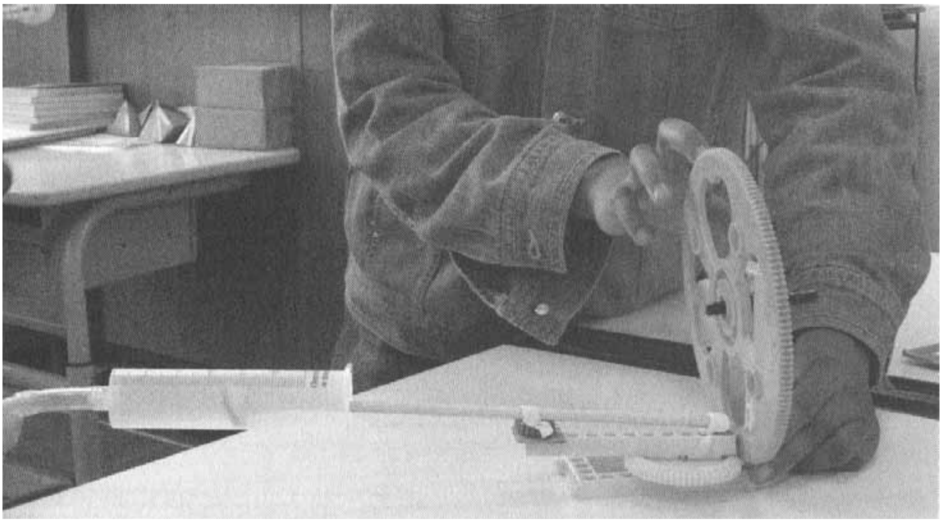
Stage 2 : Changing the rotation plan

We have from now on the means to maintain the coming and going motion of the piston without using human strength and this is due to the rotation of a wheel. always, there is a new problem that crops up this wheel relies on the wooden beam being situated near to the beam, at the same height and in a horizontal plane. It cannot be in direct contact with the water in the river. The schema of the figure below explains this. It is reproduced in the table.



Here, the wheel is not vertical, (see the two preceding illustrations), but horizontal. In the same way as in the preceding example, the movement of the wheel's rotation makes the coming and going movement of the piston. It is now necessary to add a second wheel, this time vertical. This is what will drive the horizontal wheel due to the current of the river.

To power the horizontal wheel, it needs a second wheel, placed vertically and sufficiently big to be in contact with the water. This is what will be powered by the current. It will be called the "leading wheel". The pupils will discover by this bias that two toothed wheels can be enmeshed one to the other in a rotational manner, when they are not situated on the same plane (see following photo). They put this in place with the Celda© kit. The first wheel is vertical and powered by the current in a rotating movement. This powers the second wheel set horizontally in an identical movement. The latter plays the role of the crank; it powers the wooden beam in a coming and going motion which allows the suction then the expulsion of the water to be drawn.



The rotation movement of the horizontal wheel (crank wheel) is obtained thanks to that of the vertical wheel (driving wheel)

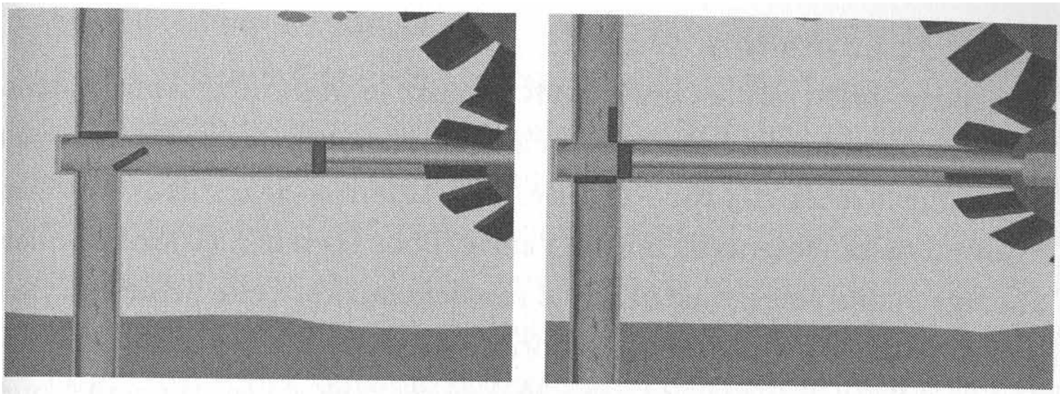
Following the outcome of these two activities, the students have now the means to solve the irrigating fields' problem. We now need to know if this solution is similar to the one imagined by the scientist al-Jazari.

Activity No. 3:
Understand the functioning of the al-Jazari pump

The animation "The al-Jazari's water pump" presented on the project site allows the students to discover and understand the suggested solution by al-Jazari during the XII century, and to compare it to their own solution. The purpose of this activity is for them to grasp the general idea about the functioning of the al-Jazari pump (in particular, the role played by the valves and the principle of double suction) and to lead the students to describe the different components of the pump, as well as their role played in the river water routing.

The role of the valves

The pump invented by al-Jazari is composed of a piston moving inside a cylinder and of valves allowing the fluid to enter and exit the pump – they replace today's water taps used by students.



This animation extract shows the piston rotating by the slider crank mechanism. When the rod moves backward (left drawing), the first valve opens and lets the water from the river flow in by way of suction. The forward movement of the rod pushes back the piston, causing the valve to close (Right drawing). The water is then pushed backwards, leading the second valve to open, causing the water to flow upwards into the upper pipe, under the pressure of the piston.

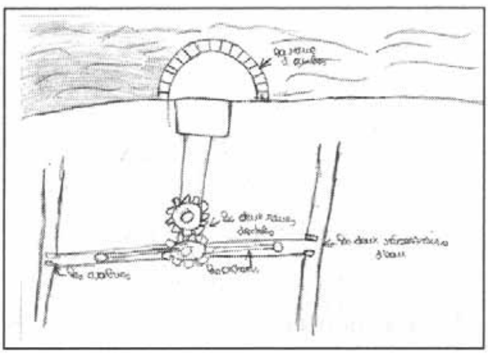
When the piston moves towards the right (Left drawing), this creates a pressure drop in the cylinder; the valve rises up with the pressure from the suction of the fluid, allowing the cylinder to be filled up. When the piston moves towards the left, the fluid inside the cylinder is put under pressure, causing the suction valve to close up, preventing the suction of the fluid. The delivery valve rises up under the pressure, causing the fluid to flow towards the delivery pipe (Right drawing). The shift of the piston is obtained through a rotating movement of a gear wheel (the crank wheel), powered by several other wheels, with the last wheel placed under water in the river, being powered by the current.

Second step: the double suction

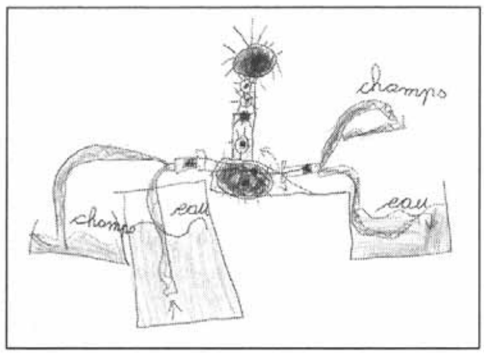
In fact, the al-Jazari pump is composed of two identical suction systems: while a piston creates a suction effect on one side of the crank wheel, on the other side, a second piston pushes the water out of the cylinder. The advantage of this mechanism is discussed in class.

Stage 3 : the number of wheels

There is another difference, which concerns the number of wheels. In the al-Jazarî pump, the vertical wheel driven by the river is not directly linked to the horizontal crank-wheel for these two wheels are situated at a distance further away from each other. To link them, al-Jazarî uses a beam and a supplementary small vertical wheel. This small wheel is engrained in the horizontal crank-wheel and linked to the big wheel by the intermediary of the fixed beam at the centre of these two wheels: the vertical big wheel turns under the effect of the river current, with it, it drives the beam which turns the small vertical wheel that in turn drives the horizontal crank-wheel. Finally, the pupils have no problem in retracing the different parts of the pump and their roles in the transfer of the water, as is witnessed by the following drawings:



Marcelle's drawing (CM2)



Kevin's drawing (CE2)

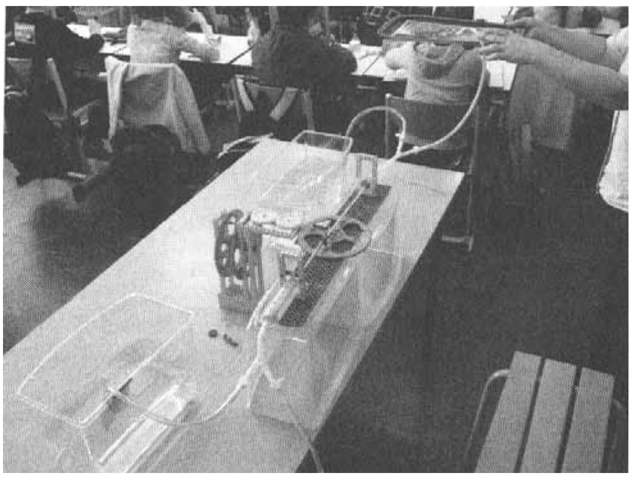
This series of activities is undertaken by the realisation in class of al-Jazari's pump with the help of the teacher. There you find the double suction, the assembly of the vertical wheel (the wheel driven by the current) with several horizontal wheels. The valves are replaced by the taps used during the first activity, and the pistons of the syringe's by the wooden beams in the second. The pump thus realised by the role of the model but with the following modifications:

— the leading role not being in direct contact with the water, had to be driven by hand;

— the piston roundels not being perfectly adjusted to the reservoir of the syringes, the suction was not perfect and the quantity of water recovered was small;

— the taps were not replaced by valves, the operation of the pump necessitated the involvement of several people.

These inconveniences and the constraints that they were under (no river in the classroom, no valves etc.) were discussed in class and made clear to all. The construction is a tenable support for reasoning and an opportunity for all to make an association with "hydrostatic" part of the pump and the "mechanics". It also gives the opportunity for the pupils to explore other systems for the elevation and carriage of water (such as Archimedes, scoop pump, etc) as a written exercise and to compare them with the al-Jazarî pump.


The details of the pump constructed in class

The pupils are now ready to send a letter to Nabil and Fadilla, in which they can describe in great detail the machine that they conceived and constructed. The problem of drawing the water from the river has given them the opportunity, in a concrete fashion, to visit one of the best technical inventions in the history of Arab science.

Note

1. You can draw water by suction with the piston of the syringe and a pipe (or straw). But be aware that you cannot raise the water to an infinite height. Any further than 10 metres high the atmospheric pressure on the water surface is no longer sufficient to compensate for the pressure exercised by the water in the pipe (or straw).

The favourite game of Nabil and his sister Fadila was to resolve the enigmas which occurred when they were observing what happened around them, or in them. They were more passionate about this, than others of their time were, a little magic was about them, like the day when they were trying to think of a machine that would draw up water for them.

It all started with their favourite walk along the riverbank. It was hot that day. They decided to leave the little dry path and went down into the middle of the reeds. Their feet in the water, Fadila closed her eyes while delighting in damping her face and neck. Seeing her, Nabil, always ready to tease, suddenly had an idea. He wanted to agitate her and started by splashing her, making windmills with his arms on the water's surface.

— Stop it right now Nabil, you are such an idiot!

— Didn't I do what you wanted? Are you not refreshed now?

Fadila, furious, climbed up the riverbank to seek refuge:

— I am soaked, but cunning as well! Up here you can't splash me.

Nabil stopped directly. Effectively, even with the most vigorous of windmills he could not reach his sister. Puffed out, he went further into the rushes. In front of her scowling brother, Fadila came down from her refuge and approached him laughing:

— So Nabil, you're in the huff!

— No, not at all, I'm thinking! I am thinking about inventing a machine to soak you, even up there!

What a good idea! It could water the fields, it would be more useful than annoying me! Come on stop making that face, I am going to help you. Firstly, we have to make a windmill on the riverbank that will take the water from the surface of the river. That you know how to do, because you know about windmills!

And Fadila was trying to dry her wet hair. Nabil replied to her with a grimace, then said:

— After that, we have to push the water further on. But how can we do it?

Fadila put her hand on his arm to signify to him, to be quiet. Coming out from behind the rushes, a man with a turban on and a blue overcoat came to sit down near them. He observed the course of the river quietly then spoke to them with a smile:

— I have been watching you since you were on the riverbank. Did you know that your games provide some interesting experiments and that you have had some good ideas? I am called al-Jazari and I have made the machine that you tried to imagine. If this interests you, I can explain to you how it works. Come on!

The man got up and took out from his coat some plans with toothed wheels, beams and pipes on. Nabil's and Fadila's eyes shone with curiosity. They got up in one bound and followed the man who disappeared with them into the rushes.

What happened next has not come down to us, it was such a long time ago, the memory is lost! It only remains that al-Jazari was the first to conceive the ingenious machine to pump water . . . And in one way or another, as he accompanied Nabila and Fadilla, he can accompany you today and all those who ask the same questions. In one way or another. . .

The still

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Introduction to Arabic alchemy

General outline

The word “alchemy” is composed by the Arabic definite article “al” and the Greek word “khemeia” or “khymeia,” who fundamentally designed the art of the smelter. According to the authors of Antiquity and the Middle Ages, the word covers four composers that did not live at the same time: the process to make the noble materials – gold, silver, secondarily precious stones and purple – from base materials (transmutation); a theory of the matter that justifies this process; a medical application of the transmutation process to the human body; in some particular contexts a spiritual application to the transmutation of the soul.

Alchemy was born at the beginning of our era by the Greeks in Egypt, but it was the savants of Islamic countries who gave it its definitive form, such as the West knows it.

It was conceived through art and professions. In Antiquity, the goldsmiths and dyers had some successes in producing things resembling gold and silver, gems and the colour purple. Some philosophers thought that in imitating nature (mimesis), in knowing the best material (the four elements) and its rules for combining (the universal sympathy), One would achieve imitation by transmutation. Alchemy is the forerunner of our modern chemistry.

The Greek alchemists are divided into two schools. Some (the pseudo-Democrats) worked as metallurgists in producing coloured alloys, others (Marie the Jew, Zosime) worked by decomposition (analysis) and re-composition (synthesis). They remove the bodies by sublimation and distillation a volatile principle (a spirit) that they fix on a substrate.

Transmutation is well understood as impossible. This is why Greek alchemy has religious connotations, the success of the operations depend on the good wishes of the divinities.

Greek alchemy was transmitted very early to the Muslims. According to legend, the young prince Khâlid ibn Yazîd was initiated into alchemy by the monk Morennius, a pupil of Etienne of Alexandria. The Arab-Islamic world made alchemy a positive and structured science profiting from the richness of materials from an immense empire, from its technological diversity, Indian and Chinese traditions, whose transmission is not yet well known.

The history of Arab alchemy unfolds in four periods.

The first (VIII-IX centuries) is that of the apocryphal translations and works.

You can see there the design of a new theory of the metal's constituents composed of a principle that it can rust, sulphur, and a principle that it melts, mercury. The different properties physio-chemical of the metals depend on the proportion and the purity of its constitution.

The second period (IX – X century) coincides with the attributed works of Jâbir Ibn Hayyân (le Geber of the Latins). Jâbir composed mathematically the material and the chemical reactions and perfected the techniques of their decomposition and composition.

The third period is that of al-Râzî (865-923/4). One should give him the classification of the thoroughness of substances (alum, salts, spirits etc.) from operations of (washing, coagulation, distillation, sublimation, solution, creation) and of devices (crucibles, cones or retorts, stills, aludels, furnaces or heaters).

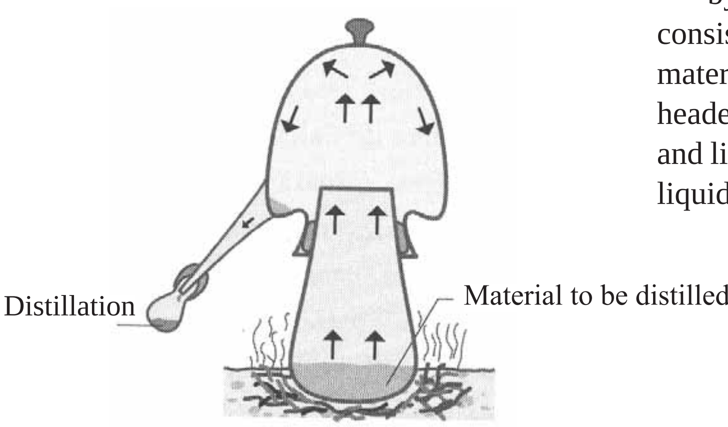
Lastly, the fourth period is that of Ibn Sînâ (Avicenne) (980-1037), who realised there was a link between alchemy and the teachings of Aristotle.

From the IX century, the Latin West, which had forgotten about alchemy for a thousand years, rediscovered it through its Spanish translators. In 1144, Robert of Chester known as Moriennus. In the second half of the XII century, translated the major part of Arab alchemy into Latin. It considerably influenced natural technology and philosophy.

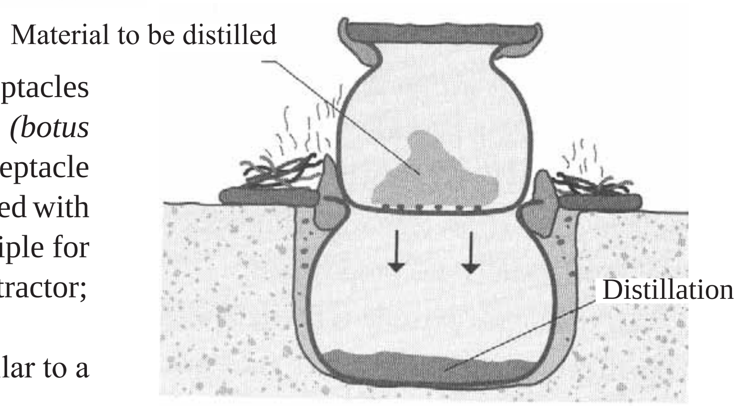
A technique of Arab alchemy: distillation

Alchemists developed distillation in the field of decomposition of substances, that is to say their purification. In Latin, *distillare,* means "to flow drop by drop". The alchemists distinguished three types of distillation:

— by the top, made by a still, consisting of a jar, where the material to be distilled is put, a header where the vapours condense and liquefy, a discharge pipe for the liquid and a receptacle;



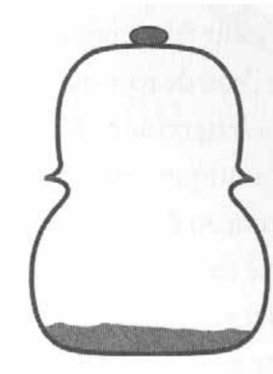
— by the bottom, in two receptacles one on top of the other *(botus barbatus)*, the upper receptacle having a lid and its base pierced with small holes. This is the principle for a couscoussiere or a juice extractor;



— through a paper filter similar to a coffee filter

The last technique has a long history. For isolating light parts of pitch or desalination of seawater, they held fleeces of wool above a cauldron. The fleece absorbed the vapour and then wrung it out to extract the liquid.

To make mercury from cinnabar (HgS), the chemist Dioscorides (I century) decided to put the mineral in a metal bowl (the forefather of the cucurbit) on which there was an inverted clay cup (the forefather of the marquee). If this was heated, the mercury vapours would condense on the sides of the cup. In Greece, this cup was called, *ambix*, which became the Arab definite article *al.* to form the word alembic.



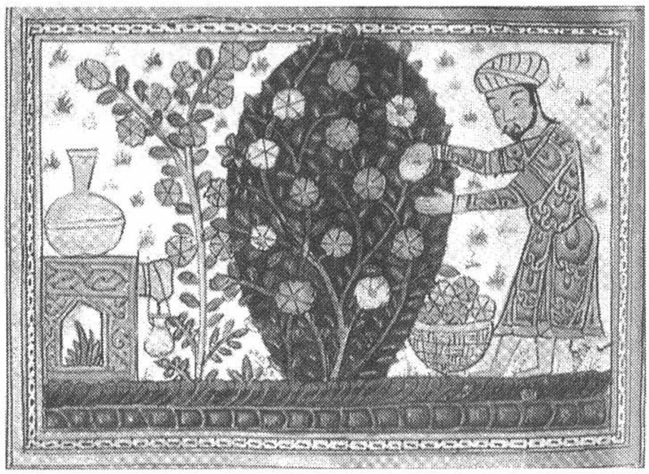
It was the Greek alchemists, in particular Marie and Zosime, that transformed this piece of equipment- wannabe into a true alembic by superimposing the top over the bowl to stop spillages and giving it a discharge tube. The vapours condense on the walls of the top gathering in a ring shaped edging and egress via the discharge tube. To isolate the substances whose boiling point is a little higher, it needs a device to cool it down. You can keep the top cool with sponges.

The alembic is the favourite apparatus of the Arab alchemist. With it you can distil corrosive substances, which will give to the XIII century our mineral acids; mineral oils and petrol, which will produce the fires of war; and with an extended production of plant juices, perfumes and essential oils.

Here, for example, two examples of the process taken from the book *Livre du serviteur* (a “manual for the laboratory assistant”) of Abu-l-Qâsim alZahrâwî (Abulcasis):

To purify water: “To purify unclear water. Take a large pot and on the top of it place two crossed lengths of wood put on them a fleece of pure wool, which has been washed several times. Light a small fire underneath the pot and the liquid will imbibe the fleece as a vapour rising out of the pot, squeeze it out and keep it, do this for as long as there is liquid in the pot.”

To industrially make rose water in a bain-marie: “You know that rose water that is made with wild roses, which have grown without being watered, have a better odour than those that have been grown domestically which are grown in cultivated places and irrigated [. . .] Take a copper cauldron such as is used by dyers, place thereon a pierced lid the holes of which can be used by alembics, fill the cauldron with water and light a fire underneath it made with vine shoots or wood of a similar nature, and distil it and when the distillation is at its mid point, you have to cover the throat of the fire until the distillation is complete and in the place of the wood put coal, the water will have more odour.”



If the alchemists from Arab countries had put in their alembics all sorts of minerals, vegetables, and even animals, they do not appear to have distilled wine. Religious reasons could have intervened. It was in the XIIth century, in Southern Italy, when the vines were particularly juicy, that the alchemists had the idea to put the wine in an alembic. The substance that they produced was a challenge to the four elements: a water that burned, alcohol.

This discovery turned the theories on materials upside down. To take into account of this special property, they were obliged to introduce a fifth element, *quinta essentia*.

The still and the distillation of water

Objectives

Year 3

To know the names of the changes in state.
To know that each change in state has an inverse change
The solvent properties of water.
States and changes in the state of water.

College, fifth class

Solvent properties of water
Separation techniques for the constituents of a mixture: filtration/distillation.
Homogenous and heterogenous notions of mixtures.
Changes in the state of water

Reference to the science and technology program, year 3 primary school

"The material: states and changes in the state of water (fusion, solidification, boiling, gaseous state, evaporation, condensation, factors acting on the speed of evaporation)"

Reference to the physio-chemical program of the college (fifth class)

"Water in our environment, mixtures and pure bodies".

List of material for a class of 25 to 30 pupils:

6 glass balls, 6 corks, a gimlet to pierce the corks, 15 roses, preferably dried (or a packet

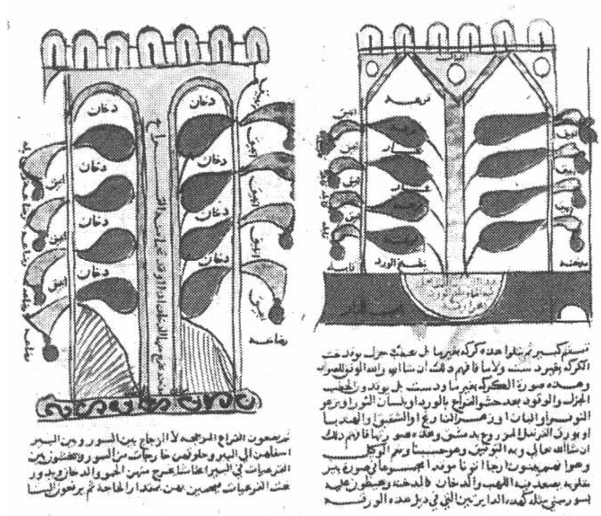
of dried lavender), a heating plate, a piece of tissue, some coffee filters, some water, salted water 20g/l, 6 pieces of transparent plastic pipe 60 cm long, a casserole, a transparent salad box, some sponges or wipes, some bowls, small transparent pots, coloured labels, permanent markers.

Woods, fruits, flowers, amber. . . we live in an ocean of odours. Some are pleasant some are not, the odours are a fundamental part of the world that we live in. They participate in our conception of reality and they remind us of past events. The domestication of odours was one of the most beautiful quests in history. From the first times in ancient Egypt, man has tried to isolate the innumerable flavours of flowers, roots, barks, and resins to make ointments and perfumes. The first techniques were rudimentary; the products whose odour they wanted to capture were ground and boiled then impregnated with a grease of some sort. You obtained a sort of aromatic pâté in which the smell was found trapped. Towards the end of these times, techniques got better and they discovered how to isolate an odour (e.g. vegetation), it was possible to capture the odours of vegetation with water or alcohol vapour. The alembic was conceived on this basis for the discovery of this process, which was called “distillation.”

Therefore the alembic is the piece of equipment that allows us to distil; it acts to separate, by heat, in an enclosed area, aromatic oils, locked in flowers, leaves, roots, etc. The steam captures the essence of the substances then forms condensation when cooling down.

A rudimentary alembic, a vase with a lid on – in the form of a cone – was already in use by the Chaldean alchemists (II century B.C.) to prepare perfumes. But it was not until much later, at the end of the VIII century, that the alchemists of Islamic countries, in the quest for the philosopher's stone (al-iksir in Arabic, the origin of the word "elixir"), who were passionate about the distillation process improved the functioning capability of the apparatus to make it into a more like modern day alembic.

It constituted a vase (a retort) containing the aromatic liquid, which had a beak to run into a recipient. You heat the liquid in the retort. After a few minutes, the aromatic vapours leave the retort and are fed into the beak. This is colder than the inside of the retort; condensation is formed and runs out as a liquid into the recipient. For example, in the case of a mixture of flower petals and water, the steam produced captures the essential oils which forms condensation then runs out of the beak.



Following the example of their illustrious predecessors, the pupils are going to emulate them in discovering the alembic in making rose water perfume (or lavender water). This will introduce them to the process of distillation. The sequence suggested for the class is in three parts:

— the first part, the problem of desalination of seawater shows distillation as a technique for the separation of mixtures;

— the second part, the history of the alembic and the contribution of the savants from Islamic countries to perfect it will be the subject of a written exercise;

— third part, a more technological approach leads the pupils to make a simple alembic allowing them to make perfumed waters from flower petals.

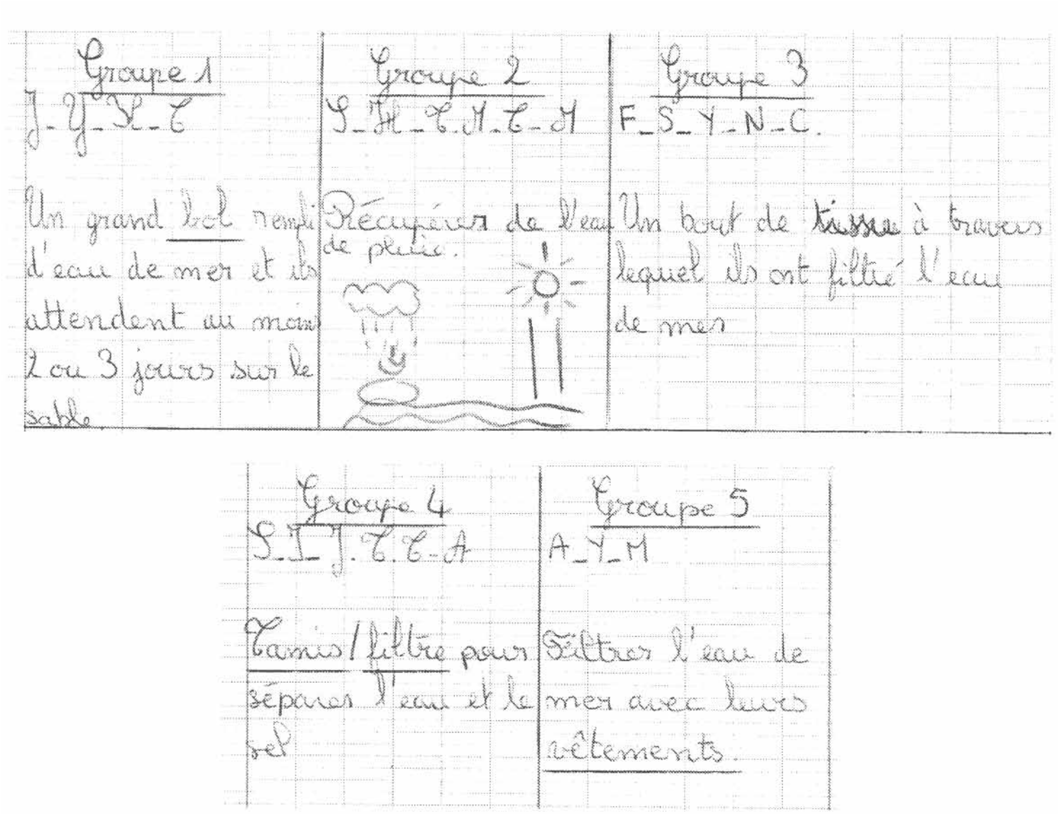
How to obtain clear water from seawater?

Water represents 72% of the total of the Earth's surface but nearly all of this water (97%) is salty. From early times, man has therefore sought to desalinate it, so that he obtains clear water and salt. Already in the IV century B.C., Aristotle had suggested to sailors to distil seawater to obtain drinking water from simple "boilers" installed on their boats. These boilers rested on the principle of distillation: seawater was heated in a pan (leaving a salt deposit behind) and the steam given off condensed and made drinkable water.

After having told them about this, we have chosen to get the pupils to work on a mixture of salted water, whose concentration, is close to that of seawater, i.e. 20 g/l. They could also test and experience personally the desalination with the help of various things that they have thought up. This separation gives a salt deposit in the bottom of the pan, whilst the steam forms condensation in the beak or the top covering and drinkable water is gathered in a receptacle.

This technique could be learned by the children as the remedy to solve the problem for the ancient mariners who were shipwrecked on a desert island, without a spring, or any water reserve, who had to find a means to drink. Many of the children knew that one can survive a few days without eating, but that it is much more difficult to go without drinking. This led them to think of the means at the disposal of the sailors to obtain drinking water. The children thought about fruits that contain a lot of moisture or even to drink seawater. But this, due to the sugared water, makes one thirsty. It is necessary therefore to envisage another source: desalination of seawater!

The problem being posed, the pupils were divided into small groups. They discuss it and make notes of their thoughts in a file. These are then presented by one member of the group to the whole of the class and set out in the form of a table (one column per group) by the teacher. A group discussion cuts this down to only one proposition per group and lets the children work on their experimental idea. Each group then carries out their experiment with the necessary equipment. The pupils record in their exercise books the experiments and propositions of the class and formulate the experiment of their group.

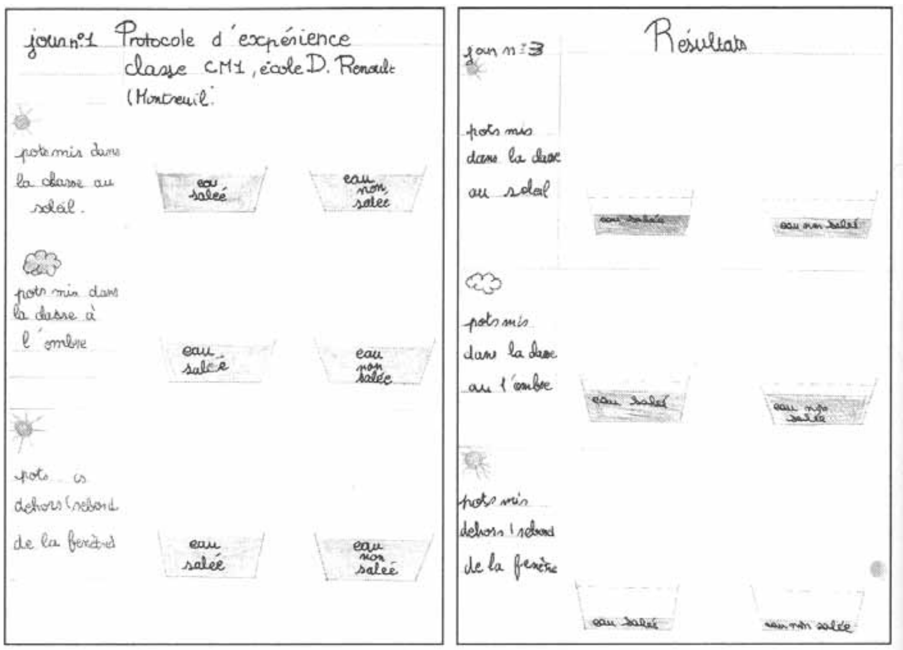


Groupe 1	Groupe 2	Groupe 3
J-Y-L-C	S_H_C.M.C-M	F_S_Y_N_C.
Un grand bol rempli d'eau de mer et ils attendent au moins 2 ou 3 jours sur le sable	Récupérer de l'eau de pluie.	Un bout de tissu à travers lequel ils ont filtré l'eau de mer

Groupe 4	Groupe 5
S.I.J.C.C-A	A_Y_M
Tamis/filtre pour séparer l'eau et le sel	Filtrer l'eau de mer avec leurs vêtements.

Extract form the exercise books representing the experiments of the propositions of the five groups of class CM1 (the capital letters correspond to the Initial of the child's surname)

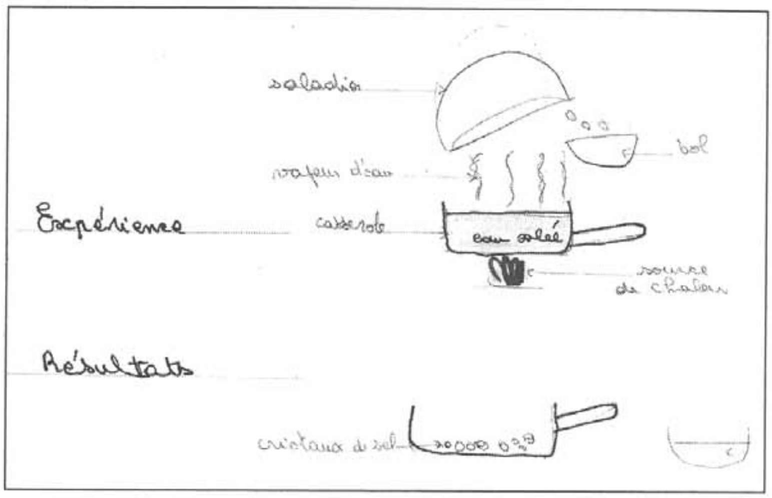
Once the assembled equipment is distributed, the groups carry out the experiments that they have proposed. At the end of this activity, the results of each group are presented to the whole class by a spokesperson. None of the solutions thought up by the pupils allow the separation of water and salt and to collect drinking water. The project of group 2 is ingenious but does not answer the question asked. Groups 3,4, and 5 got a water that was still salted; their projects however introduce the notion of the required experiment. The children are aware that they have not obtained drinkable water, but that it has become even more salted and that there is not as much liquid. Finally group 1 is on the right road for the desired process.



Group 1 test for three days of salted water
in different experimental conditions

In this experiment, two receptacles respectively containing salted water and drinking water are placed in different places: in the classroom in the sun, in the shade and outside. A mark was made to state the original level of the water (salted or not) contained in each of the receptacles. At the end of three days, the pupils noticed that the level of water had diminished in all the receptacles and that the salted water was more concentrated than it was at the beginning. Now, seeing that no-one has added any salt during these three days, it is because the salt is not so diluted. Some water has therefore evaporated without taking the salt with it, which has remained in the recipient. The pupils then discuss how they can recover the evaporated water and try to think up a different protocol for an experiment.

If the pupils have already studied the different states of the water, they will have certainly learned how to recover the water vapour, especially on the cold sides. If they discover the subject, they can conjure up the means so that the droplets of water can be recovered from the lid or an inverted covering or on glass when the water is heated. For the first time, the children try to recover the water reproducing this type of receptacle. They verify that the water droplets are not salted. To recover more drinking water, they suggest the following experiment:



Leave some time for the pupils to interpret the results and to write down the process in their exercise books, it would be beneficial to come back to the different states of the water and to precise the principal changes in state that has been undergone due to their experimentation, such as the steam and the condensation. The teacher could also make reference to other ideas not as well known such as the hydro-distillation and the alembic. The latter being the subject of documentary research developed in the second part of this sequence. On this occasion, it is opportune to tell the pupils that there are two types of distillation: the simple one that consists of separating the constituents of a mixture (as in the case of seawater), the other that comprises in changing the vapour (as in the case of the perfumed water).

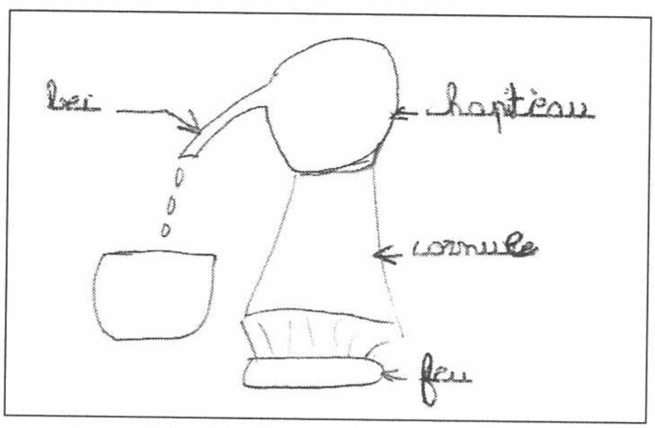
The discovery of the alembic

The practice of chemistry during the golden age of Arabic science included the introduction of laboratory instruments of which the alembic was one of the most significant. Distillation with the help of the alembic is a very old technique, which can be seen in several civilisations (Chinese, Egyptian, Greek, Roman etc.). Since then, this technique has been improved, theorised and industrialised and it still offers numerous applications in today's chemistry. Not many illustrations exist in Arab or Persian language documents. This is why we suggest starting the documentary research from the children's text, which describes the contribution of the savant al-Râzî (865-925). Reading this script will encourage the children to research text books about this savant and his contribution to the perfecting the alembic. This would give you the opportunity of writing about the preceding savants, such as Aristotle, and those who succeeded him in this domain. Two savants from Islamic countries, al-kindi and al-Zahrâwî could be the subject of deeper research:

— Yaqûb al-Kindî (801-873), who discovered numerous techniques for the distillation of aromatic plants.

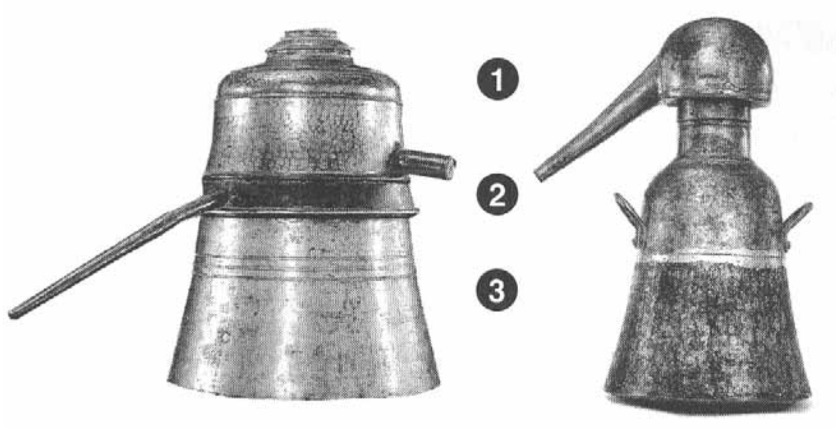
— Abû al-Qâsim Al-Zahrâwî (936-1013), who used, in his era, a cooling system.

The contribution of the Arab savants will be illustrated by the drawings of the alembic.



Claire's drawing (CM1 A, D-Renoult school, Montreal, 93)

A new documentary research done by small groups of pupils about today's alembic in order to compare it with the plan which also works well as is based on the one they have drawn. This activity allows the children to retrace a history of the alembic whilst making a chronological freeze, which shows the development of this apparatus in conjunction with the events that mark the history of the world. It is possible to couple this work with a photo of an ancient alembic together with a few words as a legend such as: caldron, cone, beak etc.



Two copper alembics from the VI-XIIth centuries.
These models are from the pharmacological collection of Turhan Baytop (1920-2002, Istanbul). According to him, this type of alembic was expanded by the central Asian Turks and from Anatolia.
The alembic on the right does not have a cooler

1: The lid. The alembic on the left has a lid to allow cooling of the aromatic vapours that occur on heating the liquid in the lower chamber. This lid is called “refrigeration”. The sides are cooled by the air temperature.
2: The cap is given a swan’s neck (beak). In the right alembic, the cap and the beak are found in the place of the lid.
3: heater.

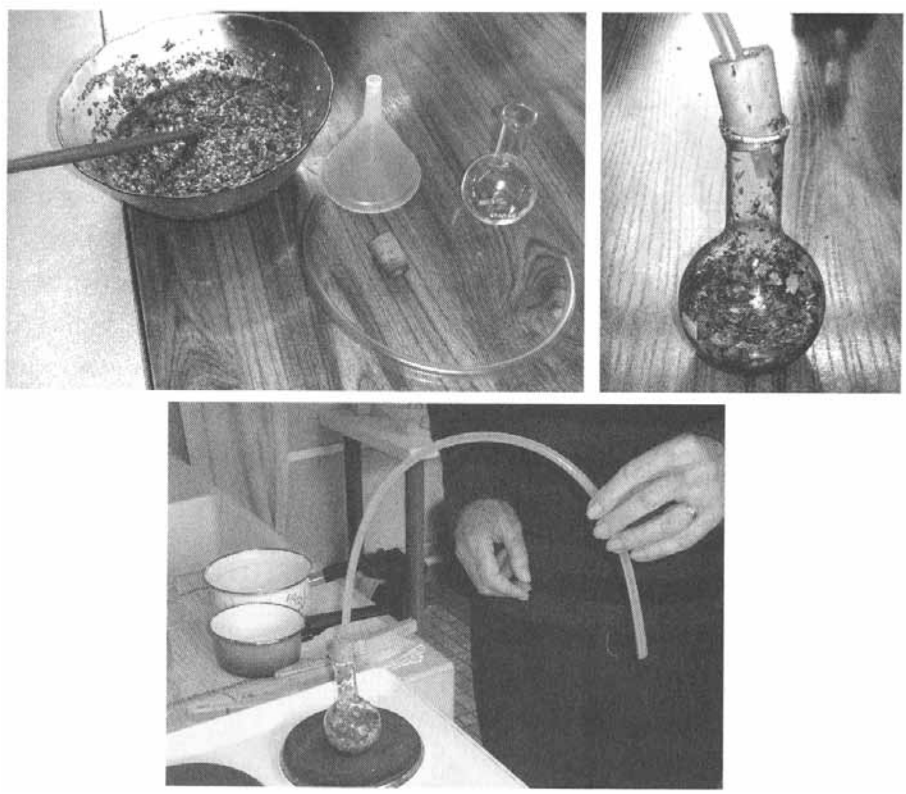
Whichever epoch is considered, you will notice that there is a common principle for all alembics: a receptacle (called, “heater” “cucurbit” or “cone”) in which the ingredients are placed, which contain the aromas that you want to extract has on it a lid (cap) fitted with a beak (or swan neck) by which the vapours form condensation. Some alembics have a cooling unit which speeds up the condensation of the steam.

The making of an alembic and perfumes

So that the pupils can properly understand the functioning of an old alembic, we suggest to them that they make a perfume with a rudimentary alembic from simple materials; corks, funnels, glass balls, transparent plastic pipes, sponges, rags, small receptacles to gather the perfume, labels, gimlets, jam jars with pierced and non-pierced lids. . .

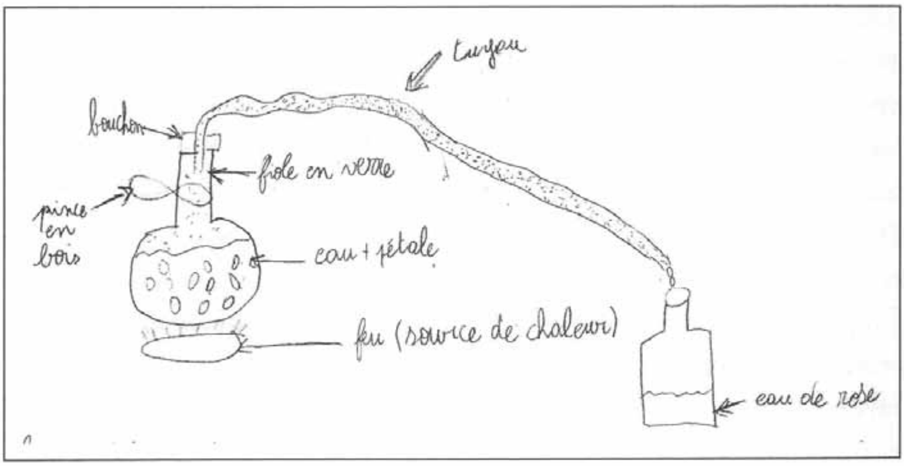
The rose is a particularly fragrant flower. We therefore choose to make some rose perfume. It's up to the pupils to find a way to extract perfume from dried rose petals brought to the class by the master. The study of textbooks has facilitated a way to form a useful experiment, as is attested by the example below.

The experiment is carried out as follows: the dried flowers are put into a salad bowl to mesh with the water. You then prepare the selected material to make in the alembic. The mixture is transferred by the funnel into the glass ball. Then a pipe of sufficient length is attached to the ball (so that the vapour has time to form condensation), and is placed on a hotplate. To help with the cooling process a piece of damp linen can be placed on the pipe. After a few minutes, the water and petal mixture begins to boil. Some vapour enters the tube where it forms condensation. The rose water is gathered from the end of the pipe.



Equipment as proposed by children of CM1
D. Renoult school (Montreal, 93)

Important recommendations: For safety reasons, it would be preferable if:
— the corks are pierced by the master, at the request of the pupils;
— the receptacle containing the roses (or lavender), and destined to be heated, should be in a glass and held with a wooden grip, a ball with a neck is preferable as it is easier to handle;
— the heating on the hot plate should be supervised by an adult;
— the receptacle where the perfume is to be collected should be transparent so that you can see the colour of the obtained liquid and its evolution during its formation.
The pupils are then invited to draw a picture of their experiment.



Sophie’s drawing – CM1
from D. Renoult school (Montreal, 93)

Note: the pupils made some perfumed water but have not mentioned the essential oil. This necessitates a second distillation and a separation by decanting.

It is helpful to show the animation on the project site here. This allows the pupils to discuss the dimensions of the beak, its cooling process, the heating of the pan and the nature of the aromatic plants used. To enlarge the project you can ask the children to describe and compare the perfumes, or to research books on the history of perfume and the ways in which it is made.

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Vocabulary

Condensation or Liquefaction : Transformation of steam into liquid

Decantation : The technique which allows the separation of particles in suspension in a liquid or a mixture of liquids of different densities. Leaving in their solutions, the most dense elements in the bottom of the container.

Distillation : Separating two or more bodies whose boiling points are different.

Evaporation : Transformation of liquid water into steam at a temperature less than 100ºC.

Hydro-distillation : Distillation with the help of an alembic of a mixture of water and an organic substance. The steam captures the essence of this substance and forms condensation in the neck of the alembic. After decantation one obtains a superior (in smell) perfume called “essential oil” containing the majority of the odorants and a inferior watery substance (aromatic water) which contain only a little.

Steam : Transformation of liquid water into steam at 100ºC at normal atmospheric pressure.

The favourite game of Nabil and his sister Fadila was to resolve the enigmas which occurred when they were observing what happened around them, or in them. They were more passionate about this, than others of their time were, a little magic was about them, like the day when a smell of flowers tickled their nostrils right in the middle of the town.

That day, they were walking with their noses to the breeze in the commercial centre of the town, which was nearby their house. They were skipping through the colourful and busy lanes, when, as they were passing by a modest little shop, a sweet smell of roses stopped them in their tracks. They glanced inside and could only see jars of different colours on the wall shelves.

Fadila interrupted her brother:

— Nabil, can you smell the same thing as me? It's exactly the same as floats out of our neighbour's garden when his roses are in bloom. But I cannot see any roses here! How can this be?

— I've no idea, but I too find it very strange, let's go in and see.

— Look, behind the counter, there's an open door, and the perfume seems to be coming from there, let's see!

They slipped in without making a noise, they went up to the door at the end of the shop. As there was nobody inside, they went in, and then they were intrigued. There were some round receptacles with small tubes coming out of them, which were centred and plopping from them perfumed steam. They were also damp sponges lying in basins not far from them. Lastly, some big panniers full of dried rose petals were lying on the ground. Fadila bent down to look at all these things, and then said to her brother:

— Roses, stoves, sponges. . . Nabil, you know that they are cooking the roses? Bur how can they capture their aroma? And what are the sponges for?

— Speak softer Fadila; you are going to get us caught.

— Yes, but answer me, I get the impression I am the only one trying to understand!

Nabil lowered the tone of his voice also:

— Not at all, I'm just trying to think, your chattering is doing me in. . .

The animated whispering of Nabil and Fadila was brusquely interrupted by the appearance in the room of a person dressed completely in white and wearing a big turban who passed in front of them with a big puff of perfumed wind. With precise gestures, he placed the dampened sponges on the top of a receptacle then he put, under the tube which was coming out of one of them, a small glass bottle. There it collected, little by little, a pink coloured liquid; and he put a drop of it still hot, with a smile, on Nabil and Fadila's hands; they were stupefied, it smelled of the roses . . Then the man introduced himself:

— I am called Abulcasis. I am interested in things in my medical and scientific life, and chemistry is one of my passions. I've been watching you for a few moments and I can see the curiosity in your eyes and I am ready today to tell you the secret of how to make rose water.

Fadila exchanged a furtive glance with her brother who encouraged her to speak:

— And could you tell us what this funny receptacle is for?

— Certainly, it's an alembic, come on let's start at the beginning. . .

What happened next has not come down to us, it was such a long time ago, the memory is lost! It only remains that it was Khalif ibn Abbas al-Zahrawi, called Abulcasis, doctor, surgeon and chemist, who had one of the best recipes for rose water. And in one way or another, as he accompanied Nabil and Fadila, he will accompany you today and all those who pose the same questions. In one way or another . . .

The balance of wisdom

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Scales throughout some episodes of its history

If we look around us, we notice straight away that we can’t do without balance and weigh, they are always needed everywhere: in industry and agriculture, in architecture and construction, in the shops, large and small, at the market and at home. That’s why scales are one of the most ancient of instruments known in the history of humanity. Its use is confirmed for the oldest of times. In effect, archaeological searches often bring up pieces of scales: arms, receptacles, springs or counterweights, the smallest and the largest, the lightest and the heaviest.

From numerous illustrations that we have come across, as those discovered in Egypt and which date from three thousand years before our time; the word “balance” is represented there by a seated man, with a hand raised above his head. Several fragments of the Book of the dead, religious Egyptian texts, also show scales. They are, the most often, scales with two equal arms having two receptacles on each end of the beam and an axis in the middle of the beam. You also often find the counterweights in the forms of animals, balls or rings.

In ancient Greece, and later in the Roman Empire era, one used two types of balances: with equal arms, and unequal arms. Illustrations and numerous fragments of them have been conserved.

It was Greece that founded the science of “simple machines”, comprising of the study of the lever, the pulley and winches, of the corner or of the screw. The lever is the most used. The great Greek savants, Archimedes (died in 212 B.C.) and later Heron of Alexandria (1st century), formulated the “principle law of the lever” : in order that the lever stays in equilibrium, the relation of the suspended weight on its extremities must be inversely proportionate to the relation of the length of its arms. The law of the lever is with the static base, the oldest branch of modern mechanics. But the balance arm is no more than a lever, this is why the science of balance and weight is founded on this law.

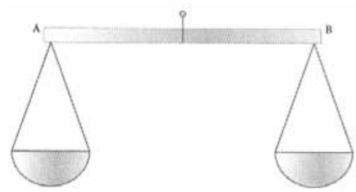


Figure 1

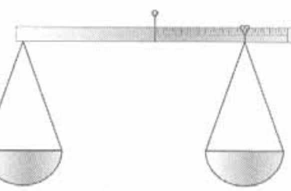


Figure 2

From Antiquity until the Middle Ages, one used two types of scales:
-Scales with equal arms, which has a beam with receptacles suspended at each of its extremities or two equal arms which rest on a support (see figure 1). The balance is in equilibrium if the weight of an object placed on one of its two receptacles is equal to the total weight of the counterweights placed on the other receptacle;
— Scales with unequal arms, which are found in two forms: a balance that is equipped with two receptacles of which one is fixed and the other, which contains the spring and counterweights, moves on the arm opposite to the first; a balance furnished with only one receptacle and one counterweight which moves the length of the arm opposite to the receptacle. On the latter, the receptacle could be replaced with a hook to weigh the objects on (see figures 2 and 3).

These two types of scales have formed the basis of all different models used in the medieval world at the time in the Muslim East and in Europe.

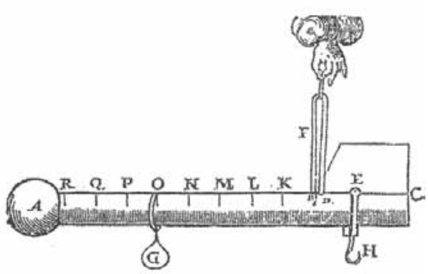


Figure 3

Numerous medieval Arab treatises have been conserved to the present day, describing different types of scales, from the most simple to the most sophisticated. From the IX century, the great mathematician Thâbit Ibn Qurra (died in 901) took an interest in the two types of scales with unequal arms described above: the qarastûn, with its two receptacles or its trammels to suspend the weight, and the qabbân, with its unique receptacle and its mobile counterweight. This second balance inspired the Muslim astronomers who invented a "balance-watch" based on the same principle and using, at the same time, the clepsydra principle (water watch).

The most interesting, among the scales with equal arms, and which are presented in different forms, is the hydrostatic scales, also called the "water balance", whose story starts with the era of Archimedes, when he discovered his famous law: "A body placed in water displaces a volume of water equal to the weight of the body submerged." A Greek legend recounts that Hiéron, the tyrant from the town of Syracuse, in Sicily, asked a savant to verify if his crown was made from pure gold or a mixture of gold and silver. In applying his law (that is to say weighing the crown in the air and then in water and comparing these weights with that of a piece of gold of the same volume), Archimedes discovered that it was made of a mixture of gold and silver (see figure 4, the weighing in water is not represented, but did take place).

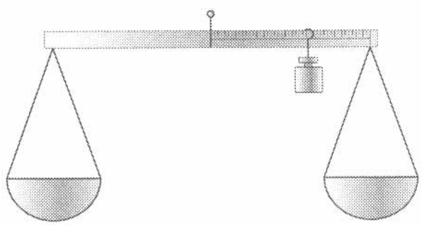
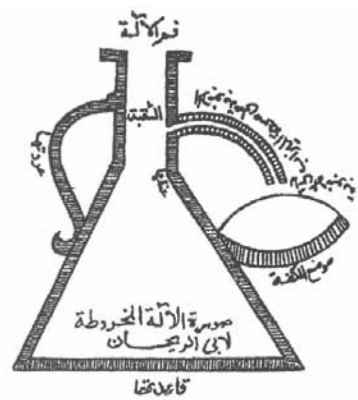


Figure 4

In the first half of the X century, al-Râzi (died in 923/4) perfected Archimedes scales. His "physical balance" with two receptacles, one of which was immobile, fixed at the end of the beam, the other could move along the length of the beam. After him, al-Birûnî (died in 1048) conceived an ingenious system to determine specific weights (also called "volume masses", that is to say the relation of the weight of each body to that of a same volume of water). It works with a receptacle combined with a counter balance: the small plaque on the right that is under the tube represents the tray of the balance).



The improvements made to the water scales were continued until the end of the XI century. As well as for scientific reasons, these improvements were motivated by the worry of the fight against false money exchangers and unscrupulous goldsmiths who had a tendency to substitute for precious metals (i.e. gold, and silver) some alloys which cost less. Among the perfectionists, there was the addition of a third tray. Two of the three trays were suspended, one above the other, so that you could weigh the subject body in the air (to get the correct weight) then in the water (to get the apparent weight, which reveals the specific weight with another body). The third, with counterweights, can move along the arms of the scales.

One of the innovators in this field, al-Isfizârî (XI century), introduced some new improvements and made a scales with five receptacles, that he called “the wise scales” or “universal scales”. This was composed of a cylindrical beam made out of iron or bronze about 2m long and had two equal arms, of two faces, of five hemispheric receptacles, of one moving weight and a fixed needle with a support, in the middle of the scales, fitted with a clever suspension system freely formed by the union of a transversal bar and a complicated formed piece called a “chisel” or “scissor”, freely attached by ropes. This suspension system was probably invented by al-Isfizârî himself.

This form of free suspension beam on a wall or on another plane vertical surface is very important. It reduced the friction effect. The scales high precision is assured by the correctly chosen dimensions of the beam and the needle, the flexing angle of the beam, the standard of the needle, etc.

All these contributions and others are brought together by the great Persian savant al-Khâzinî (XII century), the true founder of the theory of balance and weighing, in his book [Book of balance and wisdom.] In this important work, you can find the history of water scales dating from Antiquity. The author describes, in particular, the scales that would have been used by Archimedes (see figure 4) and he shows that this balance is only efficient if made out of an alloy of two specific metals. If it were made out of two different metals, it would need to have another balance. What’s more, you have to use special water, having a determined density.

Al-Khâzinî remarked also that, to obtain a precise balance, all parts have to have the correct dimensions: 4 elbows (angles) for the length of the beam (about 2m), 4 fingers (about 8cm) for the thickness in the middle of the beam (which should be more important than at the ends because it is there that the charge is at its maximum, 1 elbow (about 50cm) for the length of the needle, that is quarter of the length of the beam.

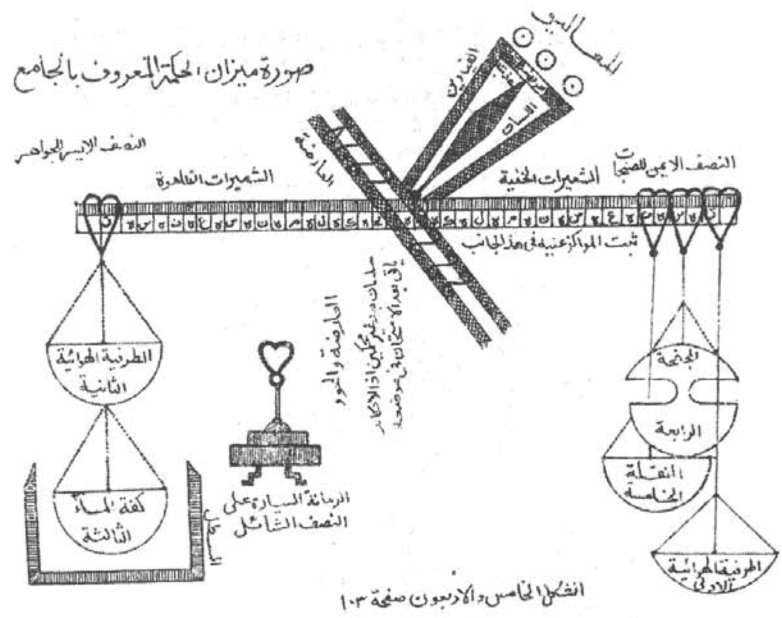


Figure 5

This savant even contributed to improve the “balance (scales) of wisdom”. He dedicated an entire chapter to the description of the different parts, the method of assembly, the usage of it and the problems to be encountered with its equilibrium and precision. One of the models he has described has been built out of wood with metal receptacles (see figures 5 & 6).

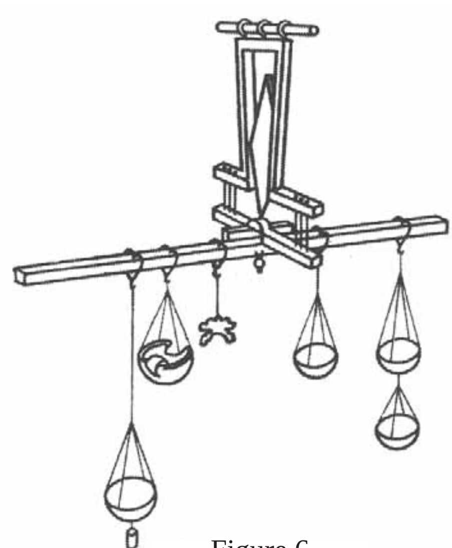


Figure 6

These scales have two receptacles for weighing a body in the air free and a third for weighing in water.

All three are fixed to the ends of the beam. To other receptacles are mobile. With the counterweights, also moveable, this allows the scales to be in a position of equilibrium before calibration and weighing. To optimise the weighing. it is necessary to use a series of crossed springs according to a geometric progression of 2 or 3, that is to say a series of crossed springs : 1, 2, 4, 8, 16, etc., or else 1, 3, 9, 27, 81, etc.

Al-Khâzinî also described in detail the method to weigh a body in water. Having weighed it, you set the scales to equal with the two receptacles and the moveable counterweights on the graduated beam. Then you reset the scales to level with the third receptacle fixed immerged in water. After that, you place the body, of a known weight, in the receptacle on the left arm, which is free in the air, and that is fixed above the receptacle immersed in the water. Next, transfer the body of this receptacle in the submerged receptacle and the counterweights in the moveable receptacle on the right. You set the balance to equal moving the non-fixed receptacles along the beam, on each side, so that the receptacles always stay equidistant to the axis. The place where you are, at the end of the operation, the moveable receptacle with the counterweights constitutes what we call the "centre" of the suspension (of a metal or a mineral), that is to say the point that corresponds to the specific weight of the object weighed (the animation on the website dedicated to the project helps you to understand the ingenuity of this.)

Repeat this exercise with several materials, the beam is graduated by the "centres" according to the order crossing the specific springs: first the metals (gold, mercury, lead, silver, bronze, iron, and tin), then the minerals, (sapphire, rubies, spinel, emerald, lapis-lazuli, rock crystals, and glass). then, you determine the particular conditions concerning the quality of the bodies studied and that of the water. It is necessary to use water from the same source and the air temperature should be constant.

The scales are also calibrated, you can weigh pairs of different metals and impure minerals. When you set the scales to equal twice, in weighing for example an alloy, the receptacle containing the alloy is found near the "centre" of the scale. If the body weighed is an alloy of metals, you can determine the percentage of the metals of which it is composed. If it is a mineral, this signifies that it is not pure or that it has hollows.

All this is only possible for alloys of two components. Al-Khâzinî notes that that the scales can be levelled in one manner only. In consequence, the specific weight of a given substance and the composition of a given alloy are determined in one way only. If the equilibrium of the scales is taken in several points on the beam or if you cannot set the scales to level, this signifies that the analysed substance is an alloy having three or more components, and if it is a mineral that it has hollows “caves”, etc. From a mathematical point of view, this problem does not have a single solution because it relates to an indefinite equation.

Finally we have to confirm that this instrument was called “universal scales”, because it allowed people to carry out different types of weighing and therefore to resolve numerous problems: problems in changes, the course of monies, the composition of alloys and mixes, and even applied mathematical problems. In effect, with the help of weights, and using pre-calculated tables, the scales allow us to resolve linear equations and some equation systems without calculation, simply reading the results on the scales.

The “balance of wisdom” were the most complete scales known in the Muslim world between the XII and the XV centuries, and perhaps even later.

Is it really gold?
On the discovery of “the balance of wisdom”

Objectives

Each material comprises of its own volume mass (in relation to the mass by volume).
One object that can turn around a fixed axis can stay equal if it is submitted to forces of which the effects are composed.
In order to turn the object, a great force has more effect than a small force applied at the same distance from the axis and an equal force has a positive effect if it is applied at a greater distance from the axis.

Reference to the project

Year 3 : “The man-made world: levers and scales, the completion of equilibrium”.
College : “To measure mass, to measure the volumes”.

Equipment used

Kitchen scales, Roberval scales, springs or graded rulers and elastic bands, graded receptacles (test tubes or beakers), water, bowls of varied mass, modelling clay.

How to distinguish gold from an identical yellow metal? This question was solved from the III century B.C. in Syracuse. In fact, it is possible to differentiate between two materials that look the same by comparing their “volume mass”, that is to say their mass for a given volume. The five receptacle scales, called “scales of wisdom”, created in the XI century by the Persian savant al-Isfizârî, is a measuring device of great ingenuity that allows, by the comparison of volume mass, to determine the nature of the material making up the majority of the objects. If the way it is used appears relatively simple (the animation on the project's website gives you a full picture), the scientific explanation of its function stays complex. In spite of everything, the physical notions puts into operation (apparent weight, mass, volume) around the principle of equilibrium. This principle is suitable for primary schoolchildren. The module that we are showing you has for its objective to make the pupils aware of the size of "volume mass" in running them through the historic stages in the building of the "scales of wisdom".

For the teacher

The volume mass of an object (measured in grams or kilograms per unit of volume) is a characteristic size of an object that depends solely on the nature of the material(s) of which it is made up. It is possible to calculate the volume mass of each object in dividing its Mass M (in grams or kilograms) by its volume V (in litres or in cubic metres). The result of this quotient (μ=M/V in g/l or in kg/l for example) is an invariant, that is to say for the same material and those that have the mass or the volume considered, the quotient M/V is a constant. The following stages comes up to this invariance and educates the pupils about the "volume mass" in a progressing fashion.

Activity 1 : To construct the size "volume mass"

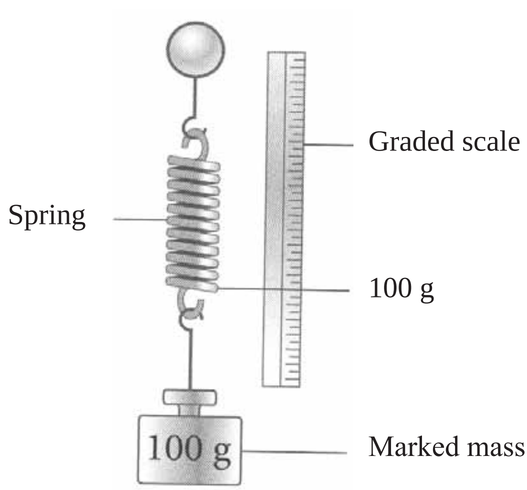
In the III century B.C., Hiéron II, king of Syracuse, commanded a crown to be made in gold, to be offered to the gods. He gave the goldsmith the quantity of gold necessary for the crown to be made from. The completed crown was weighed; its mass was identical with the amount of gold given. However, the king had his doubts: the crown did not appear to be of pure gold. Archimedes was charged to verify it but no damage was to be done to the work.

Thanks to an ingenious method, he showed that the crown was not made out of pure gold, but a mixture of gold and silver. What was this method? How did Archimedes uncover the subterfuge of the dishonest goldsmith? This module will let you uncover this.

Stage 1 : Measuring the mass

In the course of this activity, the pupils are going to discover that objects of a different nature and of an identical mass do not occupy the same place (that is to say they do not have the same volume). Each group of pupils have a glass bowl (or metal) and a large piece of modelling clay. They are told to make a bowl out of the clay which has the same mass as the glass bowl. After a few minutes of groping round they ask about the necessity for a device to measure objectively the size “mass” (measured in grams or kilograms, for example).

The idea of some scales comes to them in a fairly natural manner. A study of their books lets the pupils discover the different types of scales (scales with a beam, roman scales, springs, electronic scales etc.) and to explore the way they work. Each group of pupils studies a particular set of scales and what type of index it has (reading). The pupils then use the scales (Roberval scales, spring) given to them by the master in order to weigh the ball of clay.



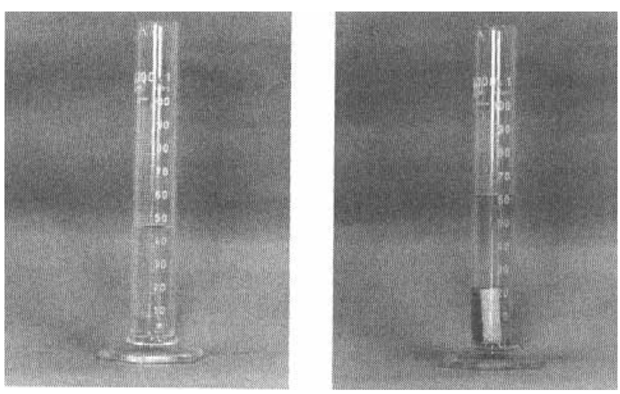
Mass of 100g suspended on a spring weight

There is a fairly simple way to measure the mass of an object. It suffices to suspend a spring (like the one on the spring weight) or an elastic band. In effect, the spring on the spring weight stretches under the weight of the object suspended from it (see previous figure). The heavier the object, the more the spring is stretched and vice versa. It suffices to calibrate it with marked levels (100g, 200g) and to establish the relationship between the tension of the spring and the value of the suspended (weighed) object. You can then find the weight (mass) of an object by reading the graded scale. After this little demonstration, you can suggest to the pupils to construct their own spring weight with the simple material. A ruler and an elastic band will do it!

The use of the spring-weight and the Roberval scales allows the pupils to get a piece of clay of the same weight as the glass bowl. They note that the two bowls are distinguished by the place they occupy, that is to say by their volume, it is possible to measure this (in litres, in millilitres or in cubic metres, for example).

Stage 2 : To measure the volumes

The pupils are now invited to think of an experiment that allows them to evaluate the area occupied by the two bowls: that of the glass and the modelling clay. This stage needs them to establish a link between the volume displaced by an object submerged and the object itself. Bring to mind some everyday occurrences such as having a bath to establish this link.



You can measure the volume of a solid in whatever shape or form
by using a graded test tube: the volume of water in
the test tube corresponds exactly to the volume of the object.

When you put an object into water, the level of the water rises to the equal quantity of the volume of the object immerged. So therefore it is possible to evaluate the volume of an object by immersion. This is the difference between the volume of water before and after immersion. In the example as shown on page 184, the volume of the object Vobject =Vwater after –Vwater before =15ml. This experiment allows the pupils to measure the volume of each of the two bowls.

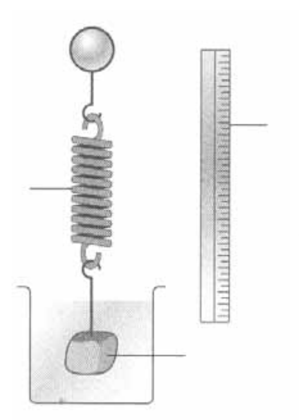
The following stage consists of getting a clay bowl as the same volume as the glass bowl which they have. In such a configuration, the two bowls are distinguished by their mass: a new use of the scales allows us to verify the same volume, the mass of the two bowls is different.

The master explains to the pupils that there is a size that allows us to know how the mass of an object varies when you change its volume, and oppositely, without having to measure the two sizes each time. This new size is called the "volume mass", unique to each material; which allows us to distinguish one from the other. Suggest to the pupils to find the value of this size for the clay.

Stage 3: The research of an invariant: the volume mass

The pupils are told to make up a protocol for an experiment to characterise the evolution of the volume for the mass of modelling clay given using the spring-weight. A first piece of modelling clay is suspended from the spring of the spring-weight. The pupils take the reading off the graded scale and record it in a dual entry table. Then the piece of clay (still on the spring) is immerged in a graded receptacle (see figure). The difference of the volume before and after immersion is also recorded in the table (see later).

The use of a graded receptacle allows us to calculate the volume of the object immersed. When the clay bowl is immersed, the spring does not stretch as much, it appears lighter.



mass (in g)	25	50	100	125	175	200
volume (in ml)	12.5	25	50	62.5	87.5	100
quotient M/V (in g/ml)	2	2	2	2	2	2

The experiment is repeated with different sized pieces of modelling clay. The pupils quickly note that there is a constant co-efficient multiplier between the value of the volume and that of the mass (here the co-efficient is equal to 2). You can therefore write that, for the modelling clay, M = 2 x V or that the relation M/V = 2 = constant. This constant is “volume mass”. It is measured in g/ml or in kg/l and is owned by each material. This size is associated to that of the density: a denser object than another (its volume mass is bigger) if, for a same mass, it occupies a smaller volume. It is possible to compare the densities of objects of an identical mass by plunging them in water.

Stage 4 : the notion of “apparent weight”

The preceding operation necessitates several successive stages: the measurement of the mass of the object, that of its volume, then the calculation of the relation of the first to the second. Al-Khâzinî’s scales (and that created by Archimedes some centuries beforehand) reduce this succession of measurements and calculations in a unique action, that of measurement, not of the volume mass itself, but of a size that is directly associated to it: the “apparent weight” of the objects.

For the master: With the preceding activity, some pupils will have noticed that when you plunge the bowl of modelling clay in the water, whilst it is suspended on the spring-weight, the latter relaxes: the object appears less heavy (see the figure above). The spring-weight (or any other weighing device) thus gives its measurement, not of the weight, but of the apparent weight. The force of gravity having a downward pull, if the object is less heavy, it is because the water is exercising an opposing force, that is to say from the bottom to the top (this is called “Archimedes’ push”). In consequence, in the water, an object possesses an inferior weight to its weight in the air. The weight of an object immersed is called “apparent weight”. This depends on the nature of the fluid that it is immersed in and even of the object itself. Also the bigger the volume of an object is, the more its weight appears to be less. Also, when two objects have the same mass, it is the one that has the greater volume that has the lightest apparent weight, and therefore the lightest volume mass. The comparison of the apparent weight of the objects of identical mass allows the comparison of their volume mass. This is also what allows us to know if they have (or not) the same nature.

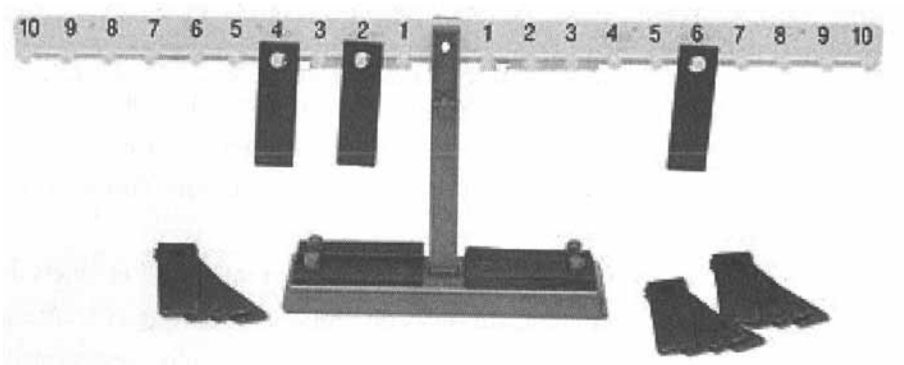
The pupils are invited to compare the apparent weight of two objects of identical mass. They choose an object of whatever mass and make a bowl out of modelling clay of the same mass. They suspend successively the two objects on the spring-weight. In the air, things change: the apparent weight of the modelling clay bowl is different to the one of whatever mass even if their mass is identical! The pupils form hypothesis on what has changed: the material, and therefore the volume mass of the two objects. From this fact, they gather that the volume of water displaced by the two objects is different. The object that has the higher apparent weight is the one that displaces the least water when it is immersed. To say it another way, it has the smallest volume, therefore the volume mass the most important (remember in effect that the volume mass μ is equal in relation to the mass M by the volume V : to equal mass, the smaller the mass the more the volume mass is big.) It is therefore possible to determine the nature of the objects of the same mass in comparing their respective apparent weight.

Activity 2 : To discover Archimedes' scales

To compare the apparent weight of the objects and to flush out the dishonest goldsmith, Archimedes used scales with equal arms called "hydrostatic scales". To bring the pupils up to the workings of Archimedes' scales it appears to us that we should go back to the equilibrium conditions of the scales.

Stage 1 : Equilibrium of the scales

For this, we use the scales called "mathematical scales" with a graded beam. Each graduation has a hook ready to hang on the plaques of identical mass.



The mathematical scale is equal when the graduated beam
is horizontal. Here, two plaques are respectively placed on the graduations 2
and 4 equalling having a plaque on the graduation 6 (Celda©).

This activity consists of a series of challenges to be taken up. Each time, the pupils have to think of a way in which they can dispose of a number of the plaques (of the same mass) to get the equilibrium. The challenges are:

— to equalise a plaque placed on the grade 3 with another plaque;

— to equalise two plaques placed on the graduation 2 with another plaque;

— to equalise a plaque placed on the graduation 6 with two other plaques without placing them on the same graduation (see photograph);

— to place a plaque on the graduation 4 and two plaques on the same graduation on the other side. Retain the equilibrium using the number of plaques you want.

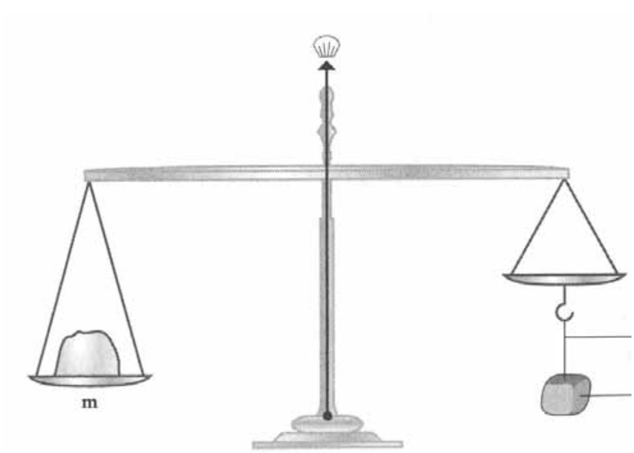
At the end of this activity, the pupils will realise that the equilibrium of the balance depends on the mass to be retained, but also their placement in relation to the rotation axis. Or yet, to equalise a mass with another twice as big, you have to place the latter twice as close to the axis.

Stage 2 : Archimedes' scales

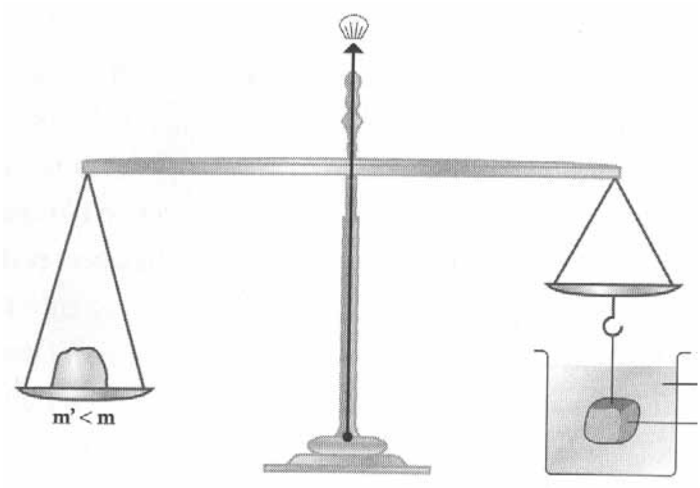
There is a relatively simple way to construct scales with equal arms. For this, you can use a rigid wooden beam that has a wire suspended in the middle. The wire is attached too a door knob, a window handle, . . . On side of this wire you suspend a small sachet containing some sand and on the other the object which you want to weigh. The pupils ensure that the balance is equal by trial and error.

Once this equilibrium has been established (see the below figure), the master asks the pupils to foresee what will happen when they immerse the object in water, whilst leaving it suspended from the balance beam, and checking their guess with the experiment. Confirming their attempt, the balance is distorted and the sand is spilled. They have to find a means to restore the balance. Several solutions are envisaged: perhaps they will refill the sachet (see following figure), perhaps they will move the sachet of sand towards the middle of the beam. Test the solutions.

The operation is then carried out again with the modelling clay bowl to the same mass as the object. When the object is not immersed, the equilibrium of the scales is obtained for the same quantity of sand in the same place as before the immersion. But things change when you immerse the bowl. The equilibrium is broken and to re-establish it, the previous solutions do not lead to the same results. If the apparent weight of the modelling clay bowl is heavier than that of the object, then the quantity of sand to re-establish it will be less, or, if it goes back to the same, the sachet will have to be moved to a shorter distance than it was previously.



When the balance beam with receptacles is horizontal,
the weight of the bowl is equal to a certain quantity of sand.



When you plunge the bowl in water, it is lighter.
The equilibrium of balance is made with less sand.

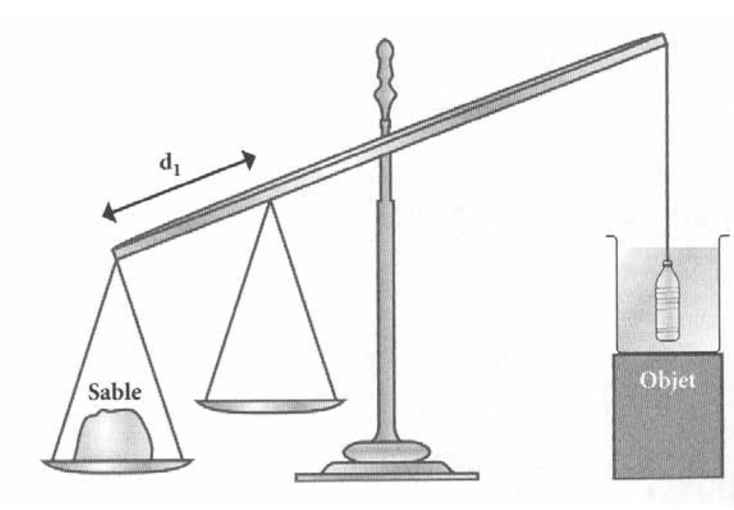
By comparing the quantity of sand used in both cases, or the distance of the sachet of sand from its original point, we obtain a reliable means to determine the nature of the two objects of identical mass without having to make successive measurements of mass then volume. This is the means Archimedes used to unmask the ruse of the dishonest goldsmith. . .

Archimedes carried out the following experiment: He put Hiéron's crown on the receptacle of the scales and the small weights on the other receptacle to obtain equal balance (equilibrium). Then he plunged the crown into water and noted that it was necessary to remove some of the weights to regain equal balance. Archimedes redid this with another object having exactly the same mass as the crown, but made solely from gold. He noted that when it was plunged into water, its weight did not diminish in the same fashion as in the preceding case and that the volume of water displaced was also different. He deduced from this that the crown could not be made solely out of gold! The goldsmith had therefore retained part of the gold that was entrusted to him and has replaced it with an identical mass of a less precious metal.

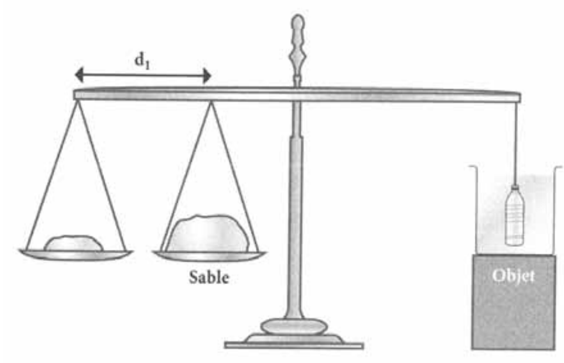
Activity 3 : In the footsteps of al-Khâzinî

Al-Khâzinî's scales allow us to get a more precise idea of the nature of the material. It comprises of a succession of levels and several receptacles. The objective of this activity allows the pupils to get to know the scales of wisdom but not to its full capacity. We will limit the study of the scales to four receptacles which allows us to classify from objects made out of the same material.

The pupils have an object again, a bowl made out of modelling clay of the same mass as the object and their lucky scales, they have an additional sachet (to gather the sand in) placed on the same side as the other sachet. The activity starts in the same way as the preceding one. The object is attached to one side of the scales. The equilibrium is obtained by placing a certain amount of sand on the other side. The object is then plunged into water, the beam leans to the side the sand is on (below). In order to re-equal (re-level) the balance, the pupils move part of the sand from the sachet furthest from the centre of the beam towards the other sachet. Equilibrium is once again obtained due to a certain quantity of sand placed in the other sachet, situated on the same side from the object at a certain distance d, from it (following page)

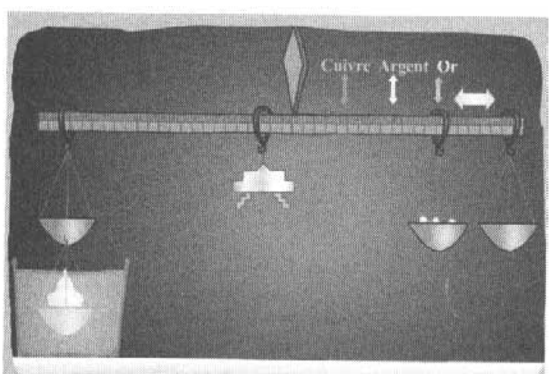


When the object is plunged into water,
its weight diminishes, the balance is not equal.



To re-level the balance, it is necessary to move a certain quantity of sand from the sachet furthest left to the right-hand sachet.

What will happen if you replace the object with the modelling clay bowl, while keeping the same quantity of sand in the same position? Knowing what happened in the previous activity, the pupils foresee that the equilibrium is going to be broken for the apparent weight of the modelling clay bowl is different from that of the object. The experiment is going to confirm this. The modelling clay and the object do not have the same volume mass, and the distance that separates the two sachets of sand is specific to each material. This is what the animation is going to confirm: the smaller the distance is between the two sachets of sand, the bigger the apparent weight is (therefore the bigger is the volume mass).



Extract from the animation: there is a relation between the distance between the two receptacles on the right and the material which makes the submerged object (on the left). This depends on the apparent weight of the immersed object, that is to say its volume mass.

In adding an additional receptacle, al-Khâzinî can determine the constitution of alloys, but the explanation of this revolutionary technique is down to the genius of al-Khâzinî and remains of a great complexity. It is not all it can do here.

The favourite game of Nabil and his sister Fadila was to resolve the enigmas which occurred when they were observing what happened around them, or in them. They were more passionate about this, than others of their time were, a little magic was about them, like the day when they were making a sort of fishing rod so that they could plunge stones in the water.

That day, Nabil and Fadila were hanging around a small lake in the rushes, not far from their hiding hole on the river bank. They had tied together several long beams of rushes so that they were rigid, before fixing some string to one of its ends. Then they had had the idea, so that the string was taut, to attach a stone and they enjoyed themselves by plunging it into the water and pulling it out as if they had caught a fish. Nabil became more and more active and finished by splashing his sister.

— Nabil stop, it's my turn! You're not achieving anything with the cane, I bet you never noticed that that the stones are less heavy when they are plunged into the water. To notice it, you have to put them in gently, like I do all the time!

— Anyway, I already know that. How do you think you can swim in water, otherwise? That would be impossible to do in the air!

Vexed by the supercilious manner of her brother, Fadila did not reply. She contented herself with issuing him with a challenge:

— Since you are so strong, can you show me how you can, without using your hands, plunge the stone in the water at the end of the string.

Very calmly, Nabil took the cane and held it out horizontally on his shoulder. Behind him, the long part of the cane balanced out the other shorter part, at the end of which was the string and the stone.

— Not bad! But watch out, now, I will change the stone, I'll put a bigger one on. What do you think, should I move the cane on my shoulder backwards or forwards?

Nabil started to slide the cane then it lost its balance, tangled up with the rushes strewn about the ground and fell in the water. Furious, he turned on his sister:

— But look, why are you giving me orders? You have not done it, with your little experiments!

Hiding her pleasure in outwitting her brother, Fadila looked at him knowingly:

— It's because you are bigger than me, so it is easier for you to make the balance!

— Oh well, if that's all, I am not a giant balance! Besides, I am going to make a proper one of them, like the merchants have! The stones that you chose will be passed without me having to do these ridiculous gymnastics. And they will have trays on the ends of the strings to put them on, as this will be easier than tying them on!

Fadila found her brother's idea so good that she had no further wish to mock him:

— Well done Nabil! And your scales, will it have two strings, eh, excuse me, two trays?

— Perhaps, but in the commercial centre, I have seen them with several trays, I wonder what they can be for. . .

— Well lets think about it and try several!

Occupied in thinking about how to achieve the object of their project, Nabil and Fadila had not seen the appearance of a man behind them whose clothes and turban was trimmed with gold threads, resplendent in the sunlight. He was carrying a leather bag full of mysterious objects and holding in one hand a receptacle full of water. On a finger on his other hand, scales were suspended. The clanks of his numerous trays finally made Nabil and Fadila turn around, surprised, exclaiming in chorus:

— Oh! what nice scales!

— From what I heard of your conversation, I think they could teach you a lot. I am called al-Khâzinî, and I have worked enjoyably to perfect this type of scales, as have several of my predecessors. I would be happy to give them to you as a present, if you are ready to learn how they work.

A big smile lit up their faces, Nabil and Fadila silently nodded their heads. Their eyes were shining in curiosity, they approached the man with the gold trimmed clothes. He put the bowl with water in next to them as well as other objects that he had with him in his bag, and started to assemble the scales trays, explaining as he went along. . .

What happened next has not come down to us, it was a long time ago, the memory is lost! It only remains that al-Khâzinî was the first one to perfect the scales with five trays, also called "the balance of wisdom". And in one manner or another, as a long time ago he accompanied Nabil and Fadila, he will accompany today all of those who ask the same questions. In one way or another. . .

Salim Al-Hassani and **Mohammed Abattouy** are respectively, President and Chief Editor of the "Foundation for Science, Technology and Civilisation" (Manchester). Both are specialized in the history of Arab mechanics.

Former Director of the Pasteur Institute in Tunis, **Amor Chadli,** is an associate member of the National Academy of Medicine (France).

Today, Regional Education Inspector, **Philippe Dutarte** has taught at the Edouard Branly Technical High School of Crétail, where he has moderated a scientific workshop related to the astrolabe, and was a trainer in IREM (the Institute for Research on Mathematics Education) of Paris-Nord.

Anne Fauche is a Scientific Mediator, Research Collaborator at the LDES (Education Laboratory and Science Epistemology) directed by André Giordan, at the University of Geneva.

Professors of Life and Earth Sciences in High schools from the Ile-de-France region, **Corinne Fortin** and **Nadia Ouahioune** are also members of the National team *La Main à la pâte.*

Robert Halleux is a Research Director for the FNRS (National Fund for Scientific Research) at the University of Lièges.

Bernard Maitte is a Professor at the University of Lille 1, where he is the Head of the Centre for History of Science and Epistemology. He is a member of UMR "Knowledge, Texts and Languages".

Helene Merle is a Senior Lecturer in Physics Education, and Instructor at the IUFM in Montpellier.

Lecturer in secondary education, **Marc Moyon** is a Doctor in History of Mathematics (Centre for History of Science and Epistemology, Lille).

Science Historian, **Mikhaylovna Rozhanskaya** is specialized in the History of Arab Mechanics and Physics.

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Discoveries in Islamic Countries

Al-Khâzinî, Ibn al-Haytham, al-Fârisî, Ibn al-Nafîs, Jabîr... are back to work! Those savants, who contributed to the Golden era of the Arab sciences, are visiting teachers wishing to feel the effervescence and the fruitfulness of a time rich in major scientific and technical discoveries. What does it matter that centuries they are separated from one another by centuries; rather, curiosity and thirst for knowledge play with the ages and contribution of the cultural diversity of yesteryears to become an additional asset for today’s era.

Discoveries in Islamic Countries is aimed at teachers for the third grade and the first years of junior high school. While allowing teachers to increase their scientific knowledge, it provides them with the educational tools to enrich their class activities.

Ahmed Djebbar is an emeritus Professor in History of Mathematics at the Lille University of Science and Technology. He is the author of many research articles and books, in particular the *Golden era of the Arab sciences* (“Le Pommier”, 2005).

Researcher in physics education, **Cécile de Hosson** is a conference manager at the University Paris Diderot-Paris 7.

Research engineer at the INPP, **David Jasmin** is the director of La main à la pâte, operation supported by the French Academy of Sciences.

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