Topic I

Characteritics of rocky planets

Magnetic Field

Cooling model of rocky planets

How big is our Solar System

Heat flow measurement

convection movement in the mantle

Cooling model for rocky planets

1. Introduction & Problem

The internal heat of a rocky planet comes first of all from the energy accumulated during the accretion phase, then from the formation of the iron core and finally from the radioactivity of the uranium, thorium and potassium present in the mantle.
When all the energy from the formation phase has been converted into heat, the planet begins to cool down.
Pb: What happens to the heat from the formation phase of a rocky planet?

2. Age of students 15 -17 years

3. Objectives

Show that the planet cools down by dissipating its internal heat up to and through the surface.
Experimental modelling and mathematical exploitation of results

4. Primary subjects

Mathematics – Physics – Earth Sciences.

5. Additional subjects

Geography – Computer Science

6. Time required 2hrs

7. Key terms

Geothermal gradient, heat flow, heat dissipation.

8. Background

Excel spreadsheet - Python

9. Materials

- 'Pétanque' ball
- Saucepan of boiling water
- Foam football
- 4 temperature sensors
- Computer with software
- Excel

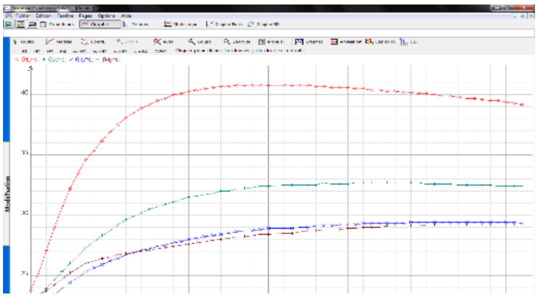
10. Procedures

- Modelling internal heat dissipation (heat flow):
One of InSight's missions is to determine the amount of heat that continues to escape from its surface (heat flow).

- Push 4 temperature sensors through the surface of a foam football and make sure they are at depths of 1 cm, 2 cm, 3 cm and 4 cm.
- Dip a pétanque ball in boiling water then place it inside the football.
- Close the foam football tightly (to limit the loss of heat).
- Note the temperature reading on the screen every minute for one hour.

Modelling:

Temperature change profile versus depth using a Spreadsheet Graph:



- Mathematical evaluation of measured heat flow data

We are looking for a possible relationship between time t and temperature T.

When the relationship is "affine", it means T = a + bt, so we talk about **a linear regression**.

Even if there is a relationship, the data measured do not usually match this relationship perfectly.

First study: Using a spreadsheet to determine a relationship between time t and temperature T

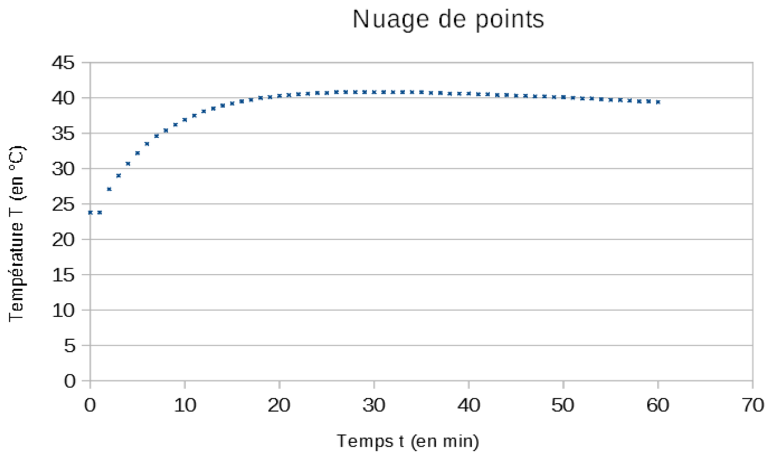
We are going to study the thermal probe database for a specific depth.

In this example, the thermal probe depth is 5 cm.

1) **Open** the file **Insight_Mars_Hp3.ods** or **Insight_Mars_Hp3.xlsx** containing the measurement data.

2) Copy the database **time *t*** and ***corresponding* temperatures *T*** to a spreadsheet.

Represent this database with a point cloud graph.



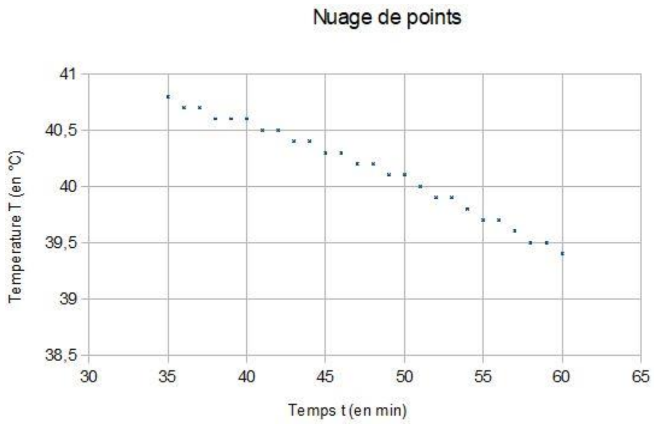
	A	B	C
1	temps	Prof 5 cm	
2	En min	en °C	
3			
4	0	23,8	
5	1	23,8	
6	2	27,1	
7	3	29	
8	4	30,7	
9	5	32,2	
10	6	33,5	
11	7	34,6	
12	8	35,4	
13	9	36,2	
14	10	36,9	
15	11	37,5	
16	12	38,1	
17	13	38,5	
18	14	38,9	
19	15	39,2	
20	16	39,5	
21	17	39,7	
22	18	40	
23	19	40,1	
24	20	40,3	
25	21	40,4	
26	22	40,5	

The second part of the curve, which reflects the cooling process (like on Earth and Mars) appears to be expressed as a straight line.

We will study how to determine this straight line and whether our data fits it.

3) In this example, measurements start at time t=35'.

Represent the database $\{(t_i, T_i), i = 35, \ldots, 60\}$ with a spreadsheet.



Looking for an affine relationship between two variables t and T means looking for a straight line which best fits this scatter graph.

The least squares method is used to find the line of best fit through an equation:

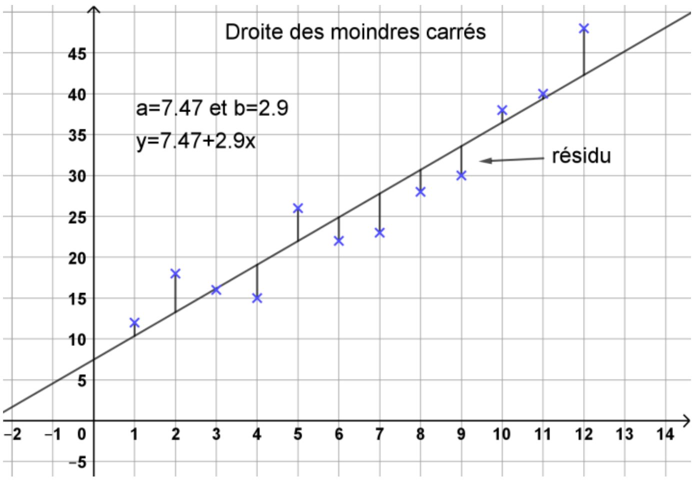
y=a+bt *with* a and b which minimise the sum of squares:

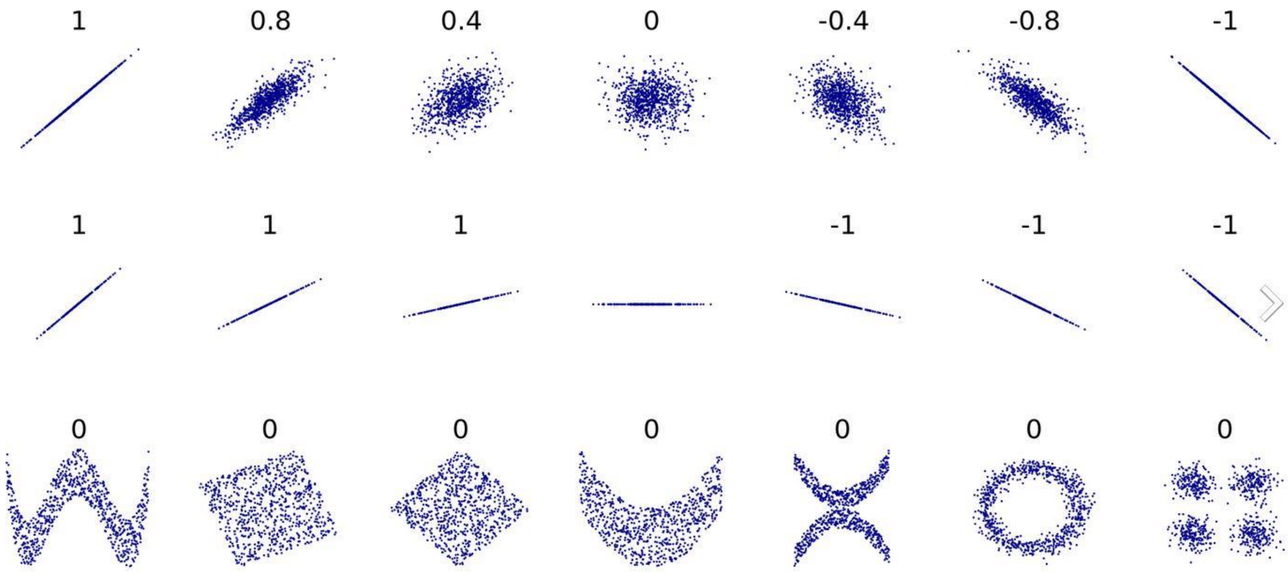
$$\sum_{i=1}^{n}\left(y_i - (a + bt_i)\right)^2$$

This straight line, which is considered to be the only one like it, is called the least squares regression line.

The idea is to determine a straight line which minimises the summed measurement of a range between the points of the scatter graph and the points with the same abscissa on this line.

The smaller the measurement, the closer to all the points of the scatter graph will be the straight line and the better the fit.





Source : hhttps://en.wikipedia.org/wiki/Pearson_product-moment_correlation_coefficient

We do not intend to study the minimisation of the range in this activity.

We call real number r the "linear correlation coefficient", defined by: $r = \frac{\sigma_{t,y}}{\sigma_t \sigma_y}$

With $\sigma_{t,y} = \frac{1}{n}\sum_{i=1}^{n}(t_i - \overline{t})(y_i - \overline{y})$, $\sigma_t = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(t_i - \overline{t})^2\right)}$

$$\sigma_y = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \overline{y})^2\right)}$$

$\overline{t}$ and $\overline{y}$ represent the average of t_i and y_i , $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} t_i$ And $\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$

The coefficient will reveal whether the fit is relevant or not, and give information on the scatter graph according to the value of r:

We will use the following numerical criteria using r²:

- if $0{,}75 \leqslant r^2 \leqslant 1$ then there is a good linear correlation between Y and t
- if $0{,}25 \leqslant r^2 \leqslant 0{,}75$ then there is a weak linear correlation between Y and t
- if $0 \leqslant r^2 \leqslant 0{,}25$ then there is a poor linear correlation between Y and t

4) Calculate coefficient r with the data temperature at a depth of 5cm.

(Caution: the Y coordinates correspond to the temperature values, T)

We are going to see whether such a straight line exists during the cooling process, which in our case took between 35 min and 60 min.

Complete the spreadsheet in order to determine the value of r and r²:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	temps	Prof 5 cm			$t_i - \bar{t}$	$T_i - \bar{T}$	$(t_i - \bar{t})^2$	$(T_i - \bar{T})^2$	$(t_i - \bar{t})(T_i - \bar{T})$	σ(t,T)	σ(t)	σ(T)	Coefficient de corrélation r	Valeur de r²
2	En min	en °C												
3			Calcul de la moyenne $\bar{t}$ des temps t											
4	0	23,8												
5	1	23,8												
6	2	27,1	Calcul de la moyenne $\bar{T}$ des températures T											
7	3	29												

If the fit is relevant, we continue...

5) If the fit is relevant, the linear regression line $y = a + bt$ can be found by calculating numbers a and b with the formula:

$$b = \frac{\sigma_{t,y}}{{\sigma_t}^2} \qquad \text{and} \qquad a = \overline{y} - b\overline{t}$$

Calculate the numbers a and b and the equation of the linear regression line fitting this scatter graph.

The existence of such a relationship between time t and temperature T at each point in time reveals the existence of thermal conductivity proper to its environment, here the foam football.

Continuation:

Let us pool the results found by each group in charge of the study for a particular depth.

We will highlight a relationship between time and heat exchange between two heat sensors.

Second study: Using Python software to determine a relationship between time t and temperature T.

We are going to study the thermal probe database for a depth of 5 cm.
We are looking for a possible relationship between time t and temperature T with the Python software and we will limit ourselves to studying linear fit.

1) Run the **Pyzo** software and **copy** files **Temps.csv** and **Temperature.csv** to the directory where the Python program is saved.

2) The following code is used to transform the csv file into a list under Python.

```
import csv

    # Les fichiers csv doivent être stockés dans le même repertoire que les fichiers python sauvegardés

    # Code pour convertir le fichier Temps.csv en fichier utilisable par Python à fournir aux élèves

with open("Temps.csv") as f:
    Temps = list(csv.reader(f))
var_list = []
list_tot = []
for i in range(0,len(Temps)):
    var_list = Temps[i]
    var_list = list(map(int,var_list))
    list_tot = list_tot + var_list
Temps = list_tot

    # Code pour convertir le fichier Temperature.csv en fichier utilisable par Python à fournir aux élèves

with open("Temperature.csv") as f:
    Temperature = list(csv.reader(f))
var_list = []
list_tot = []
for i in range(0,len(Temperature)):
    var_list = Temperature[i]
    var_list = list(map(float, var_list))
    list_tot = list_tot + var_list
Temperature = list_tot

from math import sqrt
```

The study of Python functions Map and Open is not the subject of this activity.
The time database is stored in the list “**Temps**” **(Time)**.
The temperature database is stored in the list “**Temperature**”**.**

We want to edit a program giving:
- correlation coefficient r for the range of time starting at n min and ending at 60 min (n corresponds to the time the cooling regime is reached)
- coefficients a and b of the regression line being sought if the fit is relevant

To do this, we have to determine all the elements necessary for these calculations.
(The calculation formulas are recalled on the last page)

After copying the previous code into the program, proceed as follows:

```
def equation_moindre_carre(n):
```

3) a) Complete this program to calculate the average:

- of time $\overline{t}$ noted "moyenne_t "
- of temperature $\overline{T}$ noted "moyenne_T"

b) Complete this program to obtain a list giving values $t_i - \overline{t}$ noted "ecart_t"

c) Complete this program to obtain a list giving values $T_i - \overline{T}$ noted "ecart_T"

d) Complete this program to obtain a list giving values $(t_i - \overline{t})^2$ noted "carre_ecart_t"

e) Complete this program to obtain a list giving values $(T_i - \overline{T})^2$ noted "carre_ecart_T"

f) Complete this program to calculate $\sigma_{t,T}$ noted "Sigma_t_T"

g) Complete this program to calculate σ_t noted "Sigma_t"

h) Complete this program to calculate σ_T noted "Sigma_T"

i) Complete this program to calculate the value of r when n=41.
Is the fit relevant?

4) Determination of the equation for the least squares regression line:

a) Complete this program to calculate value a.

b) Complete this program to calculate value b.

c) Complete your program so that it displays the equation for this line.

Formula:

$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} t_i \quad \overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \quad \sigma_t = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(t_i - \overline{t})^2\right)} \quad \sigma_y = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \overline{y})^2\right)}$

$\sigma_{t,y} = \frac{1}{n}\sum_{i=1}^{n}(t_i - \overline{t})(y_i - \overline{y}) \qquad r = \frac{\sigma_{t,y}}{\sigma_t \sigma_y}$

The equation of the linear regression line is: $y = a + bt$ with: $b = \frac{\sigma_{t,y}}{{\sigma_t}^2}$ and $a = \overline{y} - b\overline{t}$

The following numerical criteria will be used using r^2 :

- if $0{,}75 \leqslant r^2 \leqslant 1$ then there is a good linear correlation between Y and t
- if $0{,}25 \leqslant r^2 \leqslant 0{,}75$ then there is a weak linear correlation between Y and t
- if $0 \leqslant r^2 \leqslant 0{,}25$ then there is a poor linear correlation between Y and t

11. Discussion of the results and conclusions

We have just shown that rocky planets dissipate their internal heat up to and through the surface, which leads to their cooling.

Scientists have proposed models showing how Earth’s internal heat can be dissipated by convection, thermal conduction, volcanism, plate tectonics, etc. On Mars, heat dissipation is due largely to significant volcanism and probably more gradually by "convection".

We will explore these processes in the following activities (2, 3 and 4).

Heat flow measurement

1. Problem : What mechanisms cause the internal heat dissipation of Mars and Earth?

Hypothesis: It is hypothesised that for a solid and rigid planet, heat is transferred to the surface by thermal conduction.

2. Age of students: 14 -17 years

3. Objective:

To Understand the phenomenon of thermal conduction.

4. Primary subjects:

Mathematics – Physics – Earth Sciences.

5. Additional subjects:

Computer Science (Arduino)

6. Time required : 2hrs

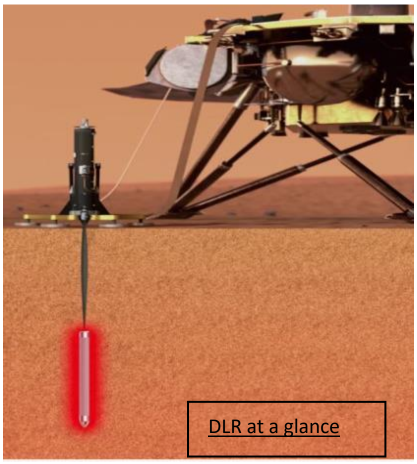
7. Key terms :

Geothermal gradient, heat flow, heat dissipation, conductivity.

8. Background :

On Earth, the temperature gradient is obtained by directly measuring the temperature at different depths in boreholes or mine shafts. This is what the InSight mission to Mars will do with its Heat flow and Physical Properties Package, an instrument known as HP3.
Once this gradient is known and the thermal conductivity of the underlying rocks is determined, scientists can deduce the heat flow at a point on the surface.
To determine the thermal conductivity of rocks, they are sampled in wells and measured in the laboratory.

On Mars, the heat flow will be measured by HP3, also known as the "mole":



DLR at a glance

Every 50 cm, the probe emits a hot pulse and its sensors monitor changes in this thermal pulse over time.

If the crust material is a good heat conductor, such as metal, the pulse will quickly disappear.

If it is a bad conductor, like glass, the pulse will cool down slowly. This tells scientists how quickly the temperature increases with depth and how heat circulates inside Mars.

The heat wave emanating from the mole's heating sheath will spread through the Martian soil, allowing scientists to determine the thermal conductivity of the regolith. Measurements should be accurate, even if the soil is not very conductive. The daily attenuation of the daytime temperature wave will provide HP3 with another way to characterise the ground's thermal conductivity.

9. Materials :

Modelling the thermal conductivity of a rock:	Modelling with temperature sensors like HP3:
- Basalt rock sample - Paraffin pellet - Flat heater	- 2 bars of rock (basalt - granite) - Heat gun. - T° Sensors - Arduino and PC

10. Procedures :

Modelling the thermal conductivity of a rock :

- Attach a sample of rock to the support (basalt, granite...)

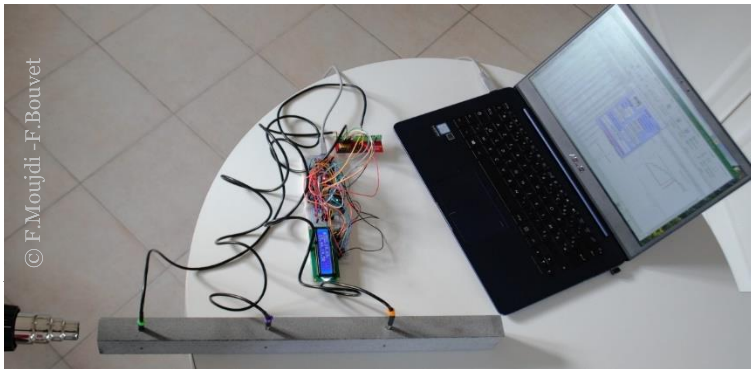
- Place paraffin pellets (3 to 5 depending on the length of the rock sample) on the rock, spacing them about 1.5 cm apart

- Light the candle and adjust the height so that the free end of the rock is over the flame.

- Observe.

Result:
The pellet just above the candle melts first and then the other pellets melt successively.

Modelling with temperature sensors like HP3:



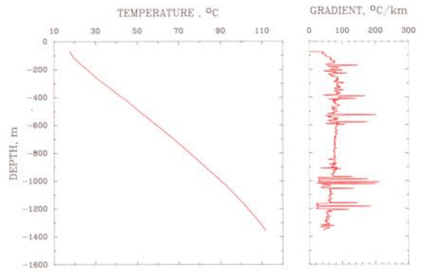
On the screen, we can follow the temperature increase for each sensor and see the heat propagate from one side of the rock to the other without moving any material.

We observe heat propagation from one side to another without any displacement of material.
This heat transfer depends on the thermal conductivity of the material passed through.

Type of material	Thermal conductivity (W/m/K)
Basalt	2.5
Granite	2.7
Peridotite	4.2 to 5.8
Limestone	1.7 to 3.3
Silver	420
Water	6

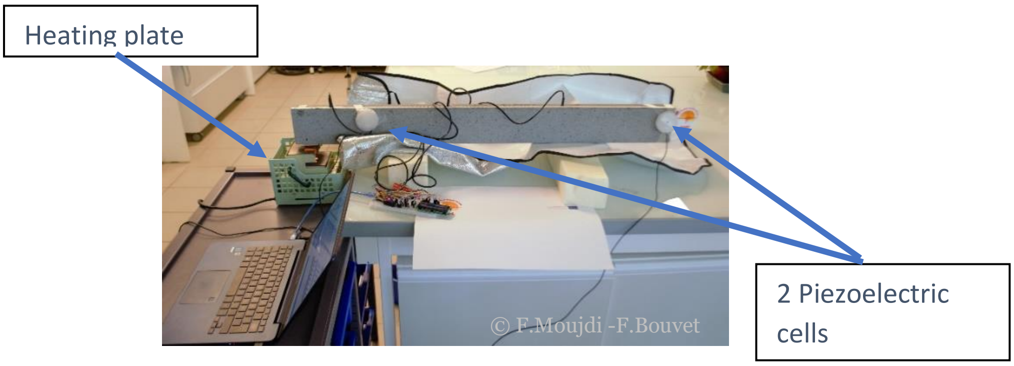
Fourier's law:

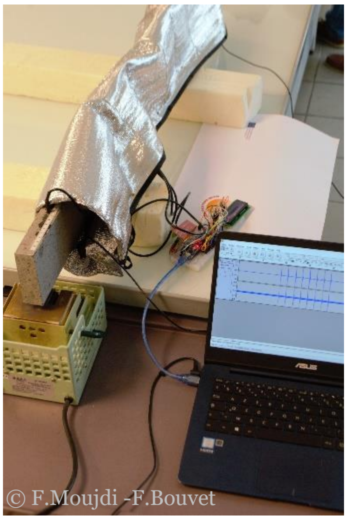
$$q = -K\frac{dT}{dz}$$



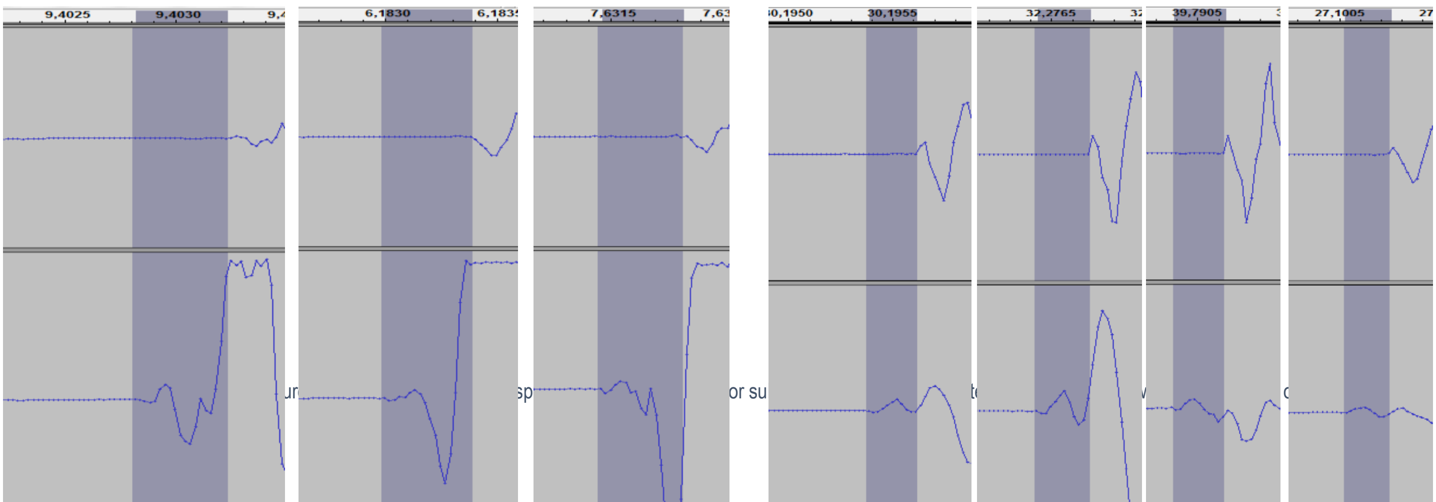
We know the conductivity of rocks studied in the laboratory.
Once the thermal gradient measured on Mars is known, geophysicists will be able to deduce the heat flow, i.e. the amount of (thermal) energy that passes through a unit of surface per unit of time (unit = J/s/m² or W/m²). Fourier's law explains that heat flow is the opposite of the product of the thermal conductivity of rocks by the temperature gradient.

Modelling with temperature sensors such and 2 piezoelectric cells :





Ambient temperature in the rock : 18,5°C **T1= 63,13 °C, T2 = 22.81°C, et T3= 20,38°C**



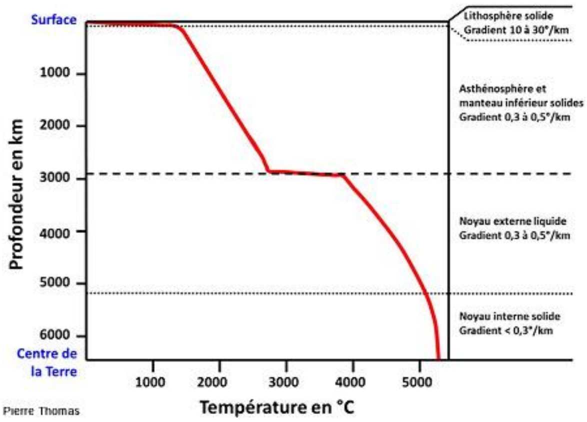
The propagation velocity of the seismic waves can be calculated in these two assemblies. The influence of temperature on wave propagation and the characteristics of the rock traversed can be determined.

11. Discussion of the results and conclusions

On Earth, internal heat is evacuated by **conduction** near the surface. But deeper down, another process known as **convection** explains heat transfer.

Using seismological data, combined with contributions from laboratory studies on the physical characteristics of terrestrial minerals subjected to high pressure and high temperature (diamond anvil cell studies), scientists have modelled the evolution of temperature versus depth.

Evolution of the Earth's internal temperature as a function of depth:



This is what the scientists of the InSight mission are trying to do.

13. Follow-up activities

Note the temperature data from the HP3 instrument and compare it with terrestrial data to determine the type of rock that constitutes the depths of Mars.

14. Explore More (additional resources for teachers)

- https://www.seis-insight.eu/fr/?option=com_content&view=article&id=175:les-autres-instruments&catid=54:la-mission-insight&lang=fr-FR

- http://planet-terre.ens-lyon.fr/article/chaleur-Terre-geothermie.xml

- The Red Planet: “*Histoire d’un autre monde*” Belin – François Forget, François Costard, Philippe Lognonné

Magnetic Field

1. Problem:

What is the mechanism behind the rapid dissipation of Mars' internal heat from the Earth ?

Hypothesis: the disappearance of Mars' magnetic field could explain its much faster heat loss than that of the planet Earth.

2. Age of students: 15 -17 years

3. Objective:

Show how an electric field can create a magnetic field and power it. and Show the role of the magnetic field of a rocky planet (earth shield).

4. Primary subjects:

Mathematics – Physics – Earth Sciences.

5. Additional subjects:

Computer science: satellite image processing with the free QGis software

6. Time required: 2hrs

7. Key terms:

Magnetic field – Electric field.

8. Background:

The magnetic field of a telluric planet is created by movements in its iron core, which is both fluid and a good conductor of electricity. Scientists hypothesise that convection within the liquid core generates an electric current which, in turn, produces a magnetic field: this is known as the "dynamo" effect.

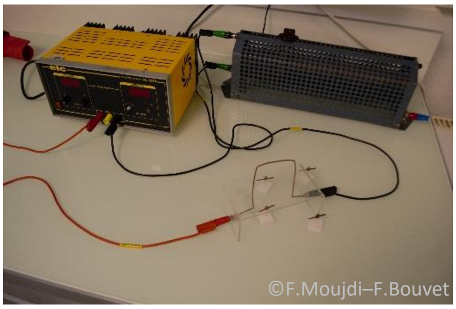
9. Materials:

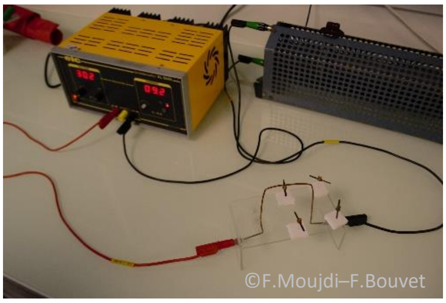
Magnetic field modelling:	Remanent magnetic field modeling:
- A power supply - Copper wire - A piece of plexiglass (about 10 cm × 10 cm) - 4 small compasses - Iron filings	- Basalt sample - Compass - 1 small compass

10. Procedures:

Magnetic field modelling:

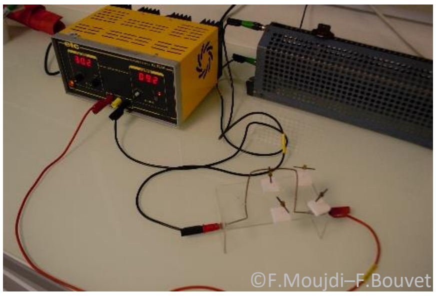
No electric current; the compass needles are aligned with the Earth's magnetic field.

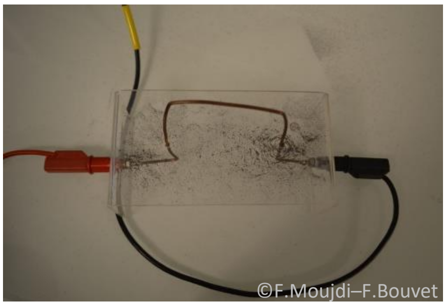




The electric current creates a magnetic field around the wire.

When the direction of the current is reversed, the magnetic field changes direction.





When the operation is repeated with the iron filings, they form a pattern of concentric circles around the wire.

On Mars, just after accretion (4.45 billion years ago), the planet had a liquid core hot enough for convection movements to generate a magnetic field like on Earth.
Mars Global Surveyor has detected the remains of an old magnetic field. Like the Earth, Mars has a magnetic crust producing strong magnetic anomalies.

<table>
<tr><th>Earth</th><th>Mars</th></tr>
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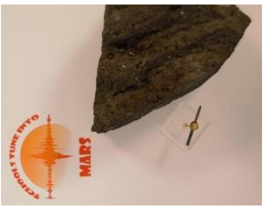
The magnetic field’s strength varies from 20 µT at the magnetic equator to 70 µT at the magnetic poles (Langlais et al.[2010]).

This magnetic field has been present since 4.5 Ma. It is variable over time and is known to have undergone polarity reversals.



On Earth, lava magnets in the opposite direction to the current magnetic field have been discovered, indicating that the Earth's magnetic field has already undergone several polarity inversions in the past.

</td>
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The MGS spacecraft identified traces of remanent magnetization at the surface and up to 400 km above and an equatorial surface field ranging from 20 to 65 nT (Langlais et al.[2010]). It produced the first complete map of the global crustal magnetic field of Mars.

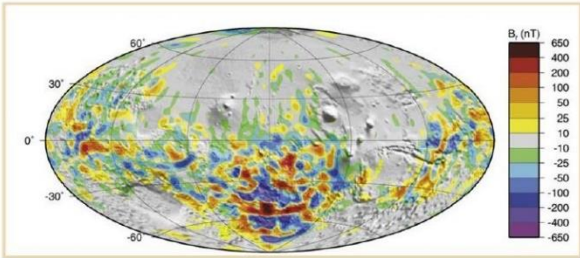

FIGURE 1.11 – Composante radiale du champ magnétique crustal de Mars (Langlais et al. [2004]).

These traces of magnetization indicate the presence of a magnetic field. In addition, the orientation of these magnets shows that the magnetic field has lasted long enough to have undergone an inversion of the magnetic poles.

The most magnetized regions are concentrated in the former southern highlands, indicating that the magnetic field was present for about 500 million years (Stevenson[2001]).

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</table>

11. Discussion of the results and conclusions

These results allow us to understand the genesis of a telluric planet’s magnetic field. Scientists assume that convection movements within the liquid core (the heat from the iron core rises until it reaches the boundary with the mantle, cools on contact with it, drops back into the core and heats up, etc.) generate an electric current which in turn produces a magnetic field: this is the dynamo effect.

Accidentally created magnetic microfields in the environment produce the electric current which, in turn, produces a global magnetic field.

The absence of a magnetic field maintained by an internal dynamo that has not worked for a long time and the absence of a thick atmosphere have made our neighbour a cold and arid world whose surface is subjected to the harmful bombardment of cosmic rays.

13. Follow-up activities

The InSight mission has embarked an InSight Fluxgate magnetometer (IFG), which will be the first magnetometer to record magnetic data directly from the Martian surface. It is sensitive to 0.1 nano-Tesla. Once the data have been received, we may observe the remnants of a former magnetic field on Mars and compare them to the data from other missions.

14. Explore More (additional resources for teachers)

- *“Terre à cœur ouvert” Pour la Science* No. 67 April – June 2010

- Mars “*Histoire d’un autre monde*” Belin – François Forget, François Costard, Philippe Lognonné

Convection movement in the mantle

1. Problem :

What are the mechanisms that cause the internal heat dissipation of Mars and Earth?

Hypothesis: It is assumed that the transport and evacuation of heat is carried out by convection.

2. Age of students 14 -17 years

3. Objectives:

Explain the different types of convection that cause heat dissipation in a rocky planet

4. Primary subjects

Mathematics – Physics – Earth Sciences.

5. Additional subjects

Computer science: Arduino code

6. Time required _2hrs

7. Key terms:

Convection

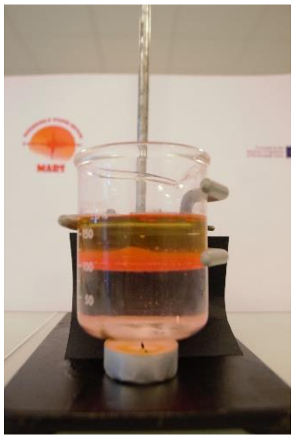
8. Background:

If a body is cooled from below and heated from above, the dense areas will be at the bottom and the less dense areas at the top. This is a stable situation that will not generate any movement. If, on the other hand, a body is heated from below and cooled from above, the dense areas will be at the top, and the less dense areas at the bottom. The cold material at the top will tend to sink and the warm, slightly less dense material at the bottom will tend to rise. This process is known as thermal convection.

9. Materials

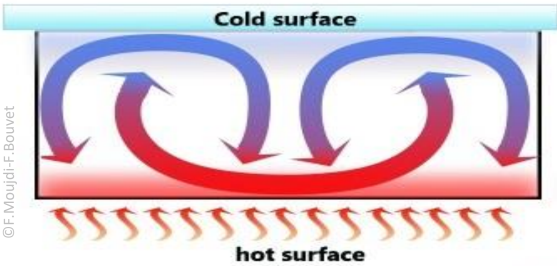
Single-layer convection modelling	Two-layer convection modelling
- Beaker - Oil - Chalk - Colouring agent	- Beaker - Oil - Coloured water

10. Procedures

Single-layer convection modelling	Two-layer convection modelling
The bottom of the heated container is hotter than the oil. The heat is transmitted to the oil, which gradually heats up. As soon as it is a little warmer and less dense than the material above, it starts to rise. As it rises, it no longer receives heat, so its temperature remains almost constant. When it reaches the top, it loses some of its heat, and sinks to the bottom without cooling down during the descent. 	If two immiscible fluids are put in a container (water at the bottom, and oil above), and heated from below, the water is subject to convection, heating the oil from below. The oil then also enters the convection process. This is referred to as "two-stage convection". 

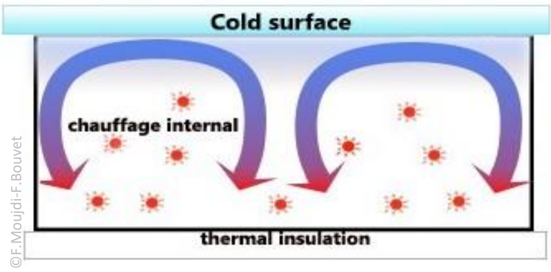
11. Discussion of the results and conclusions

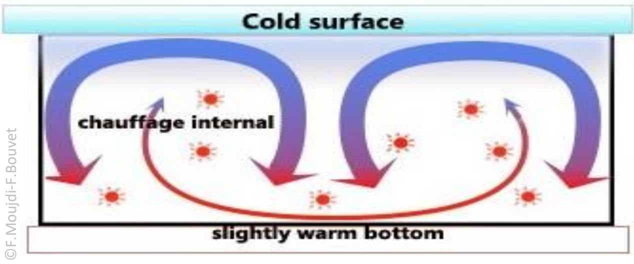
<u>Convection can take place in three possible cases:</u>



The dense, cold layer at the top sinks while the warmer layer rises. Between the two moving layers, the material moves little and keeps a constant

Red hot spots are produced in the material. Only the cold layer dives because it is denser.





This case models the mantle where the surface is slightly heated. The core releases little heat compared to the mantle's radioactivity, which releases more heat.

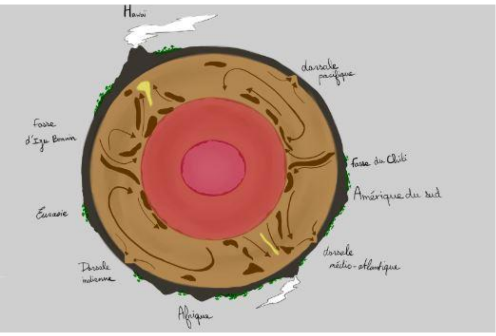
For the first 2 billion years, there was major convection in the Martian mantle, as evidenced by the planet's giant volcanoes.

Gradually, however, the most radioactive elements disappeared from the mantle, either by disintegration or because they rose into the crust with the lava.

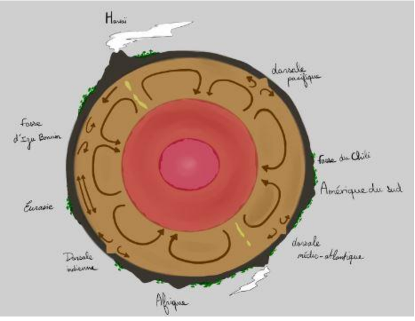
The convection didn't stop completely, though. The crust that trapped the radioactive elements now acts as a blanket heating up the mantle. By surrounding itself with an increasingly thick shell, Mars has confined its mantle under a layer of rigid, insulating materials known as the lithosphere. Mars probably still has a very hot mantle and a liquid core. The InSight mission will provide us with more information about the structure of Mars.

On Earth, nearly 40% of heat production has been concentrated in the continental crust. Scientists are divided between two models of convection:

1 convection layer :



2 convection layers :



Convection in the mantle (Silver, Carlson, Nicolas) La planète Terre Ophrys

12. Explore More (additional resources for teachers)

- "*Terre à cœur ouvert*" *Pour la Science* No. 67 April – June 2010

- Mars "*Histoire d'un autre monde*" Belin – François Forget, François Costard, Philippe Lognonné

How big is our Solar System

1. Introduction & Pb

The distances among the different planets of our Solar System are so enormous that for many students it's very difficult to compare them with the daily life distances they are used to. This activity is intended to improve the awareness of the students about the spatial relationships among the different planets in the Solar System, focusing especially in Mars and the Earth. Students will use daily life objects; this allows them to make ratio calculations. Before starting the activity, it could be useful if the students have already done the activity "Take a selfie with Mars". So, they can use the planets they have created themselves according to a fixed scale.

2. Age of students 12 - 16 years

3. Objectives

Students can:

- calculate de relative distances among the planets of the Solar System
- understand how big these distances are
- calculate distances in relation to the scale of the planets
- develop communication abilities
- (optional) use TIC to produce a semiautomatic method to calculate the distances between the model of the planets

4. Primary subjects

Earth Science

Mathematics

5. Additional subjects

Physics

6. Time required

"45 minutes + 15 minutes preparing the models"

7. Key terms.

Earth, Mars, Jupiter, planet distances, scale measurements

8. Materials

- Measuring tape (40 - 200m aprox.)
- Computer with the Google Earth™ software or similar that allows to measure distances
- Cardboards or (alternatively) balloons
- Scissors, ruler, pencil
- (optional): computer with a spreadsheet software

9. Background

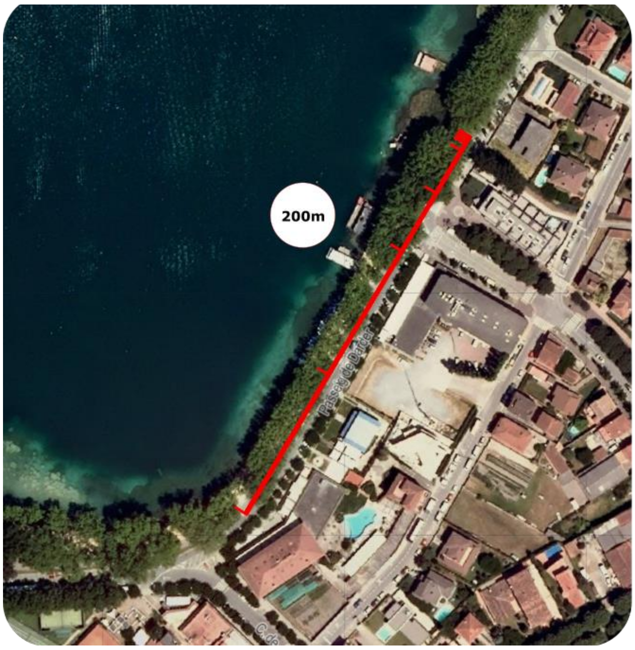
Using models is a good strategy to improve the ability of students to be aware of absolute and relative distances among planets. Relating models made of daily materials (balloons) with the real world (the planets) is a bridging activity.

The table below shows the measurements to scale that the students may need to complete the activity:

	average orbit distance (km)	equatorial circumference (km)
Mercury	57909227	15329
Venus	108209475	38024
Earth	149598262	40030,2
Mars	227943824	21296,9
Jupiter	778340821	439263,8
Saturn	1426666422	365882,4
Uranus	2870658186	159354,1
Neptune	4498396441	154704,6
Sun		4370005,6
Data from https://solarsystem.nasa.gov/		

10. Procedures

NOTE: The distances between planets are very big, take it into account to make a model in real scale.



OPTION A : (a combination with Take a selfie with Mars)

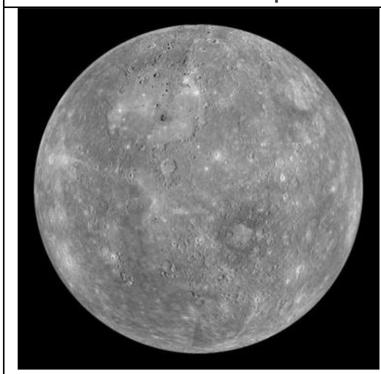
If the students have pairs of planets in real scale which they have done with balloons. Let them to calculate the real distance between the pair of planets that they have made during the activity. If the distances and spaces in the school allow you to make previous made planets in the real distance, do it.

It is easy to work with internal planets. This is so because the distances between them are shorter than for external planets. For example: if the students take a 9cm of circumference as planet Earth and a 5cm of circumference as Mars, the real distance between them is 170m. On the other hand, if they use similar size external planets, the distance between them would have to be much higher. For example: with a 7cm of circumference as Uranus, and a 6,8 cm of circumference as Neptune, they would have to place them 700m apart one from the other.

OPTION B:

Using a school corridor of which you know its length (for example 40m) the sizes of the planets would be extremely small. In this case, you couldn't use the balloons model because of tis extremely small size, You should use cards with a design of the planet to scale, Students should calculate it by handb or using an excel table. Students could make cards with the scale planet and some information about it. After this process, cards can be fixed on the corridor walls.

Students can work in groups to make the planet cards and explain their planet characteristics to other students.

Mercury	
Planet Profile	**Facts About the Planet**
Diameter: 4,879 km Mass: 3.29 × 10^23 kg (0.06 Earths) Moons: None Orbit Distance: 57,909,227 km (0.39 AU) Orbit Period: 88 days Surface Tº: -173 to 427°C First Record: 14th century BC	Mercury does not have any moons or rings. Mercury is the smallest planet. Mercury is the closest planet to the Sun. Your weight on Mercury would be 38% of your weight on Earth. A day on the surface of Mercury lasts 176 Earth days. A year on Mercury takes 88 Earth days. It's not known who discovered Mercury.
 **Source:** NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington	Size of the planet in real scale of this solar system: Scaled diameter: X,XXmm

11. Discussion of the results and conclusions

Students understand the relative distances of the planets in the solar system. This gives them a better understanding of the solar system as a whole.

Cooperation and teamwork are also encouraged.

12. Follow up activities

If you want to try the option A of the procedures, you should do "Take a selfie with Mars" activity before. Nevertheless, these tow activities are independent from each other

13. Explore More (additional resources for teachers)

https://solarsystem.nasa.gov/planets/overview/

https://space-facts.com/planets/

