PRACTICAL TEST: THE SUN, A UNIQUE ENERGY SOURCE FOR THE SOLAR SYSTEM

In the event of a manned mission to Mars, the sun appears to be the most immediately accessible source of energy. The planet is further away from the sun than Earth and, therefore, receives less energy. **We will therefore determine the surface area of solar panels that need to be deployed on the surface of Mars as part of a permanent colonization mission.**

PART I : Measuring the solar constant.

The solar constant expresses the amount of solar energy received on a 1m^2 surface located at a distance of 1 astronomical unit (average Earth-Sun distance), and exposed perpendicular to the Sun's rays in the absence of atmosphere. For the Earth it is therefore the energy flux at the top of the atmosphere. It is expressed as watts per square meter (W x m^{-2}).

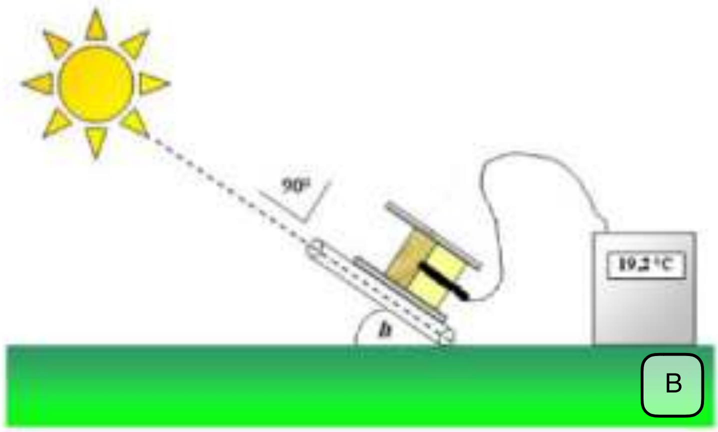


FIGURE 1: Measuring of the solar constant.
***(A)** The measuring device. It consists of a set of supports (1) with a bracket, clamps and nuts; a calorimeter (2) - an assemblage of a PVC tube, insulating foam and a brass or steel mass (3) that can be heated by the sun; a digital thermometer (4) to measure the temperature during the experiment. Note : You will use your own IESO exam board as an inclinometer, a timer and a calculator (provided).*
***(B)** Principle behind the measurement of solar constant. In order to orient the surface of an object perpendicularly to the sun's rays, it is sufficient to place a sheet behind the object and orient the object to minimize its shadow.*

Question 1: To evaluate the solar constant, the calorimeter is exposed such that the brass mass receives the maximum energy. How should the device be oriented? Select the correct answer. (Only one answer possible)

1-

2-

3-

4-

TECHNICAL EVALUATION 1 BY REFEREE

PART II : Measuring the terrestrial solar constant.

Instructions :
- Take note of the material provided to you (that of Part I).
- Orient the device such that the surface of the mass is perpendicular to the sun's rays.
- Acquaint yourself with all the parameters necessary to determine the solar constant. They are presented in the table 1 below.
- Measure the angle of the axis the device makes with the horizontal. This is the height of the sun above the horizon.
- Start the experiment. Note the initial temperature. After 10 minutes, record the final temperature.
- Bring the device to a shaded area.

After completing the experiment, enter the measured values in table 1 :

Parameters	**Symbol and unit**	**Value**
Mass	M (kg)	
Diameter of the mass	D (m)	
Thermal capacity of the mass	C_p (J x K^{-1} x kg^{-1})	
Height of the Sun above the horizon	h (°)	
Initial temperature	T_i (°C)	
Final temperature	T_f (°C)	
Duration of the experiment	Δt (s)	

TABLE 1 : Experimental parameters required to determine the solar constant.

We have taken our measurements on the surface of the Earth, but the solar constant is a calculated value that excludes the influence of the atmosphere. It is therefore necessary to apply a correction factor.

In other words, any power value, denoted $\mathbf{P_d}$, depends on the value of the solar constant **F** corrected by a factor ***cor***, which depends on the thickness and transparency properties of the atmosphere traversed. The relationship is then written as :

$$F = P_d \times cor \qquad \text{(a)}$$

Height of the Sun h (°)	**20**	**30**	**40**	**50**	**60**	**65**
Clear blue sky	2.5	2.0	1.7	1.5	1.4	1.3
Intermediate sky	4.2	3.5	2.6	2.1	1.8	1.5
Cloudy sky	5.3	4.3	3.2	2.5	2.2	2.0

*TABLE 2 : Data for the determination of the factor **cor** as a function of the thickness and transparency of the layer of atmosphere traversed.*

Question 2: The solar constant F is… (only one possible answer)
1- smaller than that which is measured on the ground and dependent on weather conditions.
2- smaller than that which is measured on the ground and not dependent on weather conditions.
3- identical to that which is measured on the ground and dependent on weather conditions.
4- greater than that which is measured on the ground and not dependent on weather conditions.
5- greater than that which is measured on the ground and dependent on weather conditions.

We assume that our assembly is flawless, though that is not the case. For example, thermal insulation problems limit the accuracy of our data. The values obtained will actually be lower than the data values from a more precise device.

Consider our system to perform as :

$$E_{solar} = M \times C_p \times \Delta Temperature \qquad \text{(b)}$$

Recall the relationship between power and energy :

$$E_{solar} = P_{solar} \times \Delta t \qquad \text{(c)}$$

The power received per unit surface area S at ground level P_d is related to the power received P_{solar} by the relationship :

$$P_{solar} = P_d \times S \qquad \text{(d)}$$

Question 3: The solar constant F can be calculated by the relationship deduced from formulae (a), (b), (c) and (d). Choose the correct relationship below: (Only one answer possible)

1- $F = \dfrac{S \times \Delta t \times cor}{M \times C_p \times \Delta Temperature}$ because F increases when S increases.

2- $F = \dfrac{S \times \Delta t}{M \times C_p \times \Delta Temperature \times cor}$ because when S increases, more energy is captured.

3- $F = \dfrac{M \times C_p \times \Delta Temperature \times cor}{S \times \Delta t}$ because F is proportional to the variation in temperature.

4- $F = \dfrac{M \times C_p \times \Delta Temperature}{S \times \Delta t \times cor}$ because F is inversely proportional to the correction factor.

The surface area of a disc can be calculated using $S = \pi \times r^2$ where S is the surface area in m^2 and R the radius of the mass M. Recall that the order of magnitude of a value is the power of 10 closest to the value. For example, 32 is closer to 10 than to 100, and thus has an order of magnitude of 10^1, whereas 74, which is closer to 100 than to 10, has an order of magnitude of 10^2.

Question 4: According to your measurements, the value of the terrestrial solar constant has an order of magnitude of :

1-10^1 W x m^{-2}.
2- 10^2 W x m^{-2}.
3-10^3 W x m^{-2}.
4-10^4 W x m^{-2}.

TECHNICAL EVALUATION 2 BY REFEREE

PART III : Measuring the solar constant across the solar system.

Measuring the solar constant in the solar system amounts to an understanding of how this parameter changes as a function of distance from the Sun.

Instructions :
- Familiarize yourself with the equipment provided.
- The light meter can move inside the tube ; you can read the distance between the light meter and the light source directly at the indicator level.
- Measure the light intensity for different distances to answer question 5.

Question 5: The solar constant is… (only one answer possible)
1- proportional to the distance to the Sun.
2- proportional to the square of the distance to the Sun.
3- inversely proportional to the square root of the distance to the Sun.
4- inversely proportional to the distance to the Sun.
5- inversely proportional to the square of the distance to the Sun.

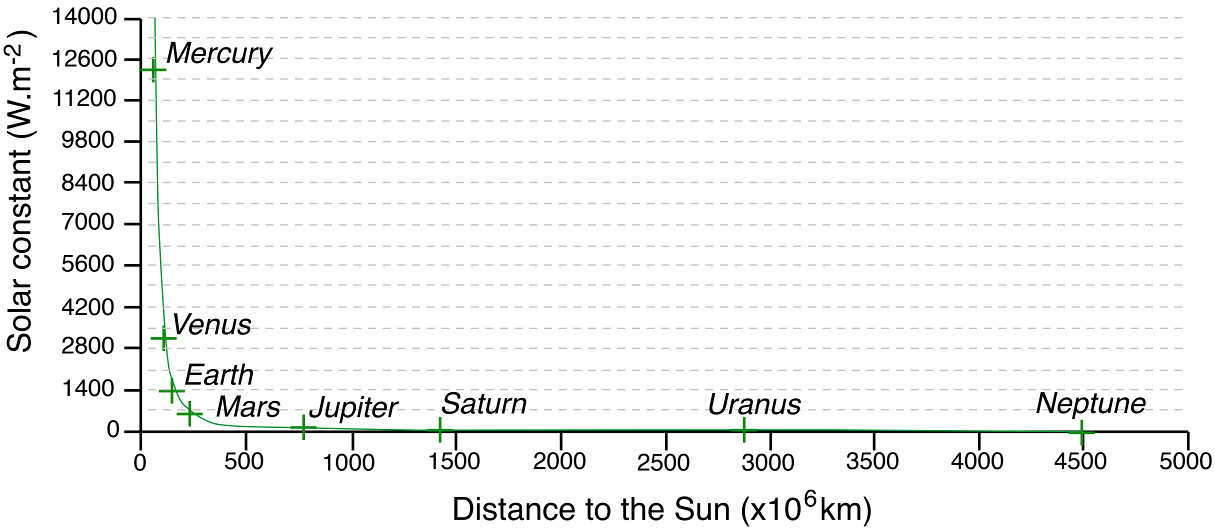
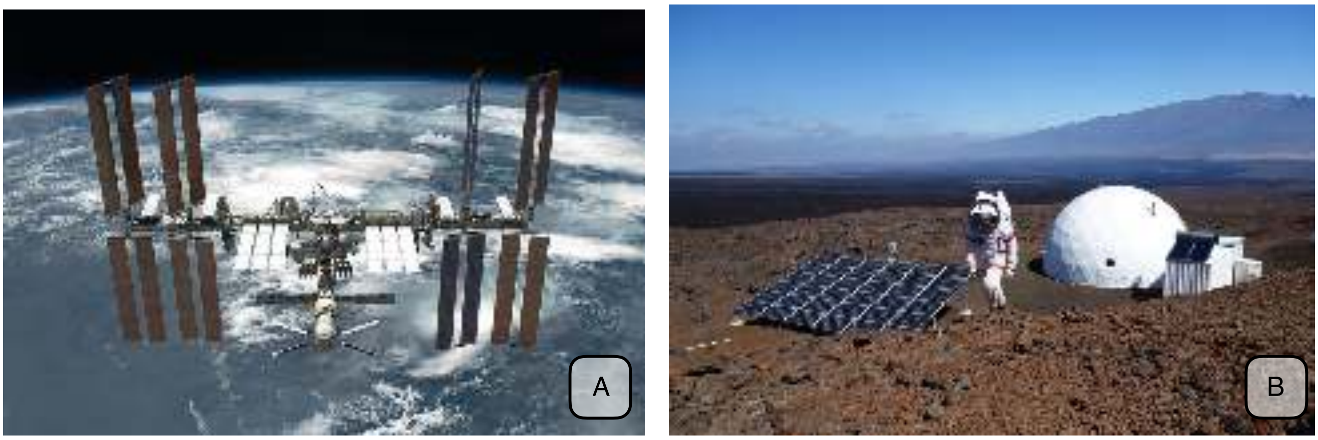


FIGURE 2 : Solar constant versus the distance to the Sun for eight planets of the solar system.

Question 6: The solar constant… (only one answer possible)
1- is about 700 W x m^{-2} on Mars, or between 22% and 28% of the solar constant on Venus.
2- is twice as large on Mars, compared to Earth.
3- is very weak for the last four most distant planets.
4- is proportional to the distance from the Sun.
5- is greater on Saturn than on Uranus because the former has a larger radius.



<u>FIGURE 3</u> : (A) Photograph of the International Space Station (ISS) in Earth orbit. It has dimensions of 110x74x30 (LxWxH in meters) and a total mass of 400 tonnes, its autonomous operation is provided by eight solar generators. Each consists of a mast surrounded by two 32m x 11m surfaces that support the photovoltaic cells. (B) Dome simulating life on Mars during the HI-SEAS program that took place on the slopes of the Kilauea volcano in Hawaii. The living conditions and thus the energy requirements for the autonomy (essentially pressurization and heating) of this Mars colonization module are similar to those of ISS.

Question 7: Based on the information in Figures 2 and 3, how many generators would be needed for an autonomous manned mission to Mars?

1- about 4
2- about 8
3- about 10
4- about 12
5- about 14
6- about 16
7- about 18