Getting Gaia Going

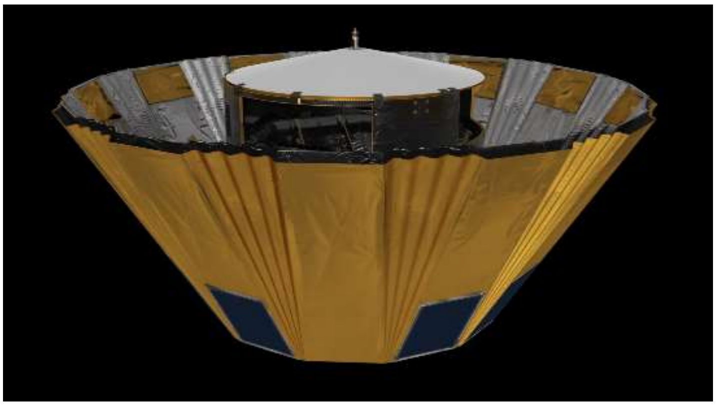
The power generated and consumed by Gaia

Power Systems on Gaia

After launch, Gaia deployed its sunshield on its journey to orbit. The sunshield is used not only to keep the instruments cool and dark but it also carries a 12.8 m^2 **solar array**. The solar array provides the spacecraft with **1,910 W** of power, which is more than adequate for the total of **1,561 W** of power required by the spacecraft. In comparison this is about the same power required for a microwave oven.

Figure 1 shows Gaia unfolding its sunshield.

Figure 1 – The unfolding of Gaia's sunshield with its solar panels on the back.



Step 1: What is the meaning of *power* and what SI unit is it measured in?

Power refers to the rate at which energy is used/transferred. Power is measured in Watts (W) where 1 W is equal to 1 Joule per second ($J\ s^{-1}$).

Step 2: How is the power of an electrical circuit calculated?

Power is calculated by multiplying the potential difference (voltage) and the current:

$$P = IV$$

Where:
P = Power (W)
I = Current (A)
V = Potential difference/voltage (V)

Step 3: A typical solar panel installed on the roof of a house will generate around *200 W*. How many solar panels would you need to meet the total power *required* by Gaia?

Gaia requires 1,561 W. Therefore:

$$\frac{1{,}561\ W}{200\ W} = 8$$

You would need 8 solar panels to power Gaia.

Step 4: Laptops use approximately *45 W*. How many laptops could Gaia's *solar array* power?

Gaia's solar array generates 1,910 W of power. Therefore:

$$\frac{1{,}910\ W}{45\ W} = 42$$

Gaia's solar array could power 42 laptops.

Step 5: Calculate the *surplus* power provided by Gaia's solar array and how many laptops this could power.

$$surplus\ power = 1{,}910\ W - 1{,}561\ W = 349\ W$$

$$\frac{349\ W}{45\ W} = 7.8$$

This would be enough to power 7 laptops.

Step 6: Luckily, because Gaia is powered by light from the Sun, it is free. However, if Gaia had to pay an electricity bill like most of us do on Earth, how much would its *1,561 W* consumption cost *per year*?

Assume the cost of electricity is 10 p per 1 kWh.

It is easier to work in time units of hours here. The number of hours in 1 year is equal to:

$$1\ yr = (365\ x\ 24)\ hrs\ per\ yr = 8{,}760\ hrs$$

Each year, Gaia therefore uses:

$$1{,}561\ W\ x\ 8{,}760\ hrs = 1.37\ x\ 10^7\ W = 13{,}700\ kWh$$

This amounts to a total cost of:

$$13{,}700\ kWh\ x\ 10\ p = 137{,}000\ p$$

$$137{,}000\ p = £1{,}370$$

Annual household electricity bills are around £1,000. So the cost of powering Gaia for a year would be similar to powering a house.

Step 7: Gaia is *1.511 x 10^8 km* from the Sun. How long does it take for light from the Sun to reach Gaia? Give your answer in both *seconds* and *minutes*.

Speed of light = 3.00 x 10^8 m s^{-1}

Students should recognise to use the following equation:

$$speed = \frac{distance}{time}$$

First students should make sure they have the same units for distance:

$$3.00\ x\ 10^8\ m\ s^{-1} = 3.00\ x\ 10^5\ km\ s^{-1}$$

Therefore by rearranging this equation and inputting the corresponding values we obtain:

$$time = \frac{1.511\ x\ 10^8\ km}{3.00\ x\ 10^5\ km\ s^{-1}} = 504\ s$$

$$\frac{504\ s}{60\ s\ per\ min} = 8.4\ mins$$

Step 8: Earth is located *1.496 x 10^8 km* away from the Sun. Would the time it takes for light from the Sun to reach Earth be greater or smaller than the time it takes for it to reach Gaia? Give a reason for your answer.

Students should recognise that Earth is closer to the Sun than Gaia is and would therefore receive light quicker. This is due to the following equation:

$$time = \frac{distance}{speed}$$

As the speed of light is constant, by decreasing the distance the time also decreases, giving a smaller value in this scenario.

Step 9: How long does it take for light from the Sun to reach Earth? Give your answer in both *seconds* and *minutes*.

Here students should repeat the calculations they made in Step 7 but replace the distance value.

$$time = \frac{1.496\ x\ 10^8\ km}{3.00\ x\ 10^5\ km\ s^{-1}} = 499\ s$$

$$\frac{499\ s}{60\ s\ per\ min} = 8.3\ mins$$

Step 10: How much *energy* does Gaia's solar array provide to the spacecraft in *one day*?

Here students should recognise to use the following equation:

$energy = power\ x\ time$

As 1 W of power is equivalent to 1 J s^{-1}. We must convert the unit of time accordingly:

$1\ day = (60\ x\ 60\ x\ 24)\ s\ per\ day = 86{,}400\ s$

Therefore:

$1{,}910\ W\ x\ 86{,}400\ s = 1.65\ x\ 10^8\ J$

During launch and before the sunshield with its solar panels was deployed, a **72 Ah (Amp-hour)** Li-Ion battery was used to power the satellite. Gaia has a Power Control and Distribution Unit that generates a **28 V** power bus.

Power buses are used to enable **communication** between separate components within a system in order to control the **power supply**. A potential difference (voltage) is required in order to make an electric charge flow through a component from one point to another.

On Gaia, the power bus connects all the components of the satellite and distributes the power among these components accordingly.

Step 11: What is meant by the term *potential difference* *(voltage)* and what unit is it measured in?

Potential difference is needed in order for a current to move through an electrical circuit and is measured in volts (V). It is the difference in electric potential between two places which the current moved through. If 1 J of energy is converted by moving 1 C of charge through the component, the potential difference is equal to 1 V.

The Watt-hour (Wh) is a unit used to measure the energy consumption. It describes how much energy is consumed when 1 W of power is generated for a period of 1 hour, where power describes the rate at which energy is transferred.

Step 12: Calculate the energy generated by the Li-Ion battery over one hour. State your answer in *Watt-hour* (Wh).

Note: you may want to refer back to the formula you identified in Step 2.

Here students should recognise to use the following equations:

$energy = power\ x\ time$

$power = current\ x\ voltage$

Therefore:

$72\ Ah\ x\ 28\ V = 2{,}016\ Wh$

The energy capacity of the Li-Ion battery is equal to 2000 Wh, or 2000 W for 1 hour.

Step 13: Using your answer from Step 12, calculate this energy in ***Joules.***

As 1 W is equal to 1 J s^{-1}, we must calculate the corresponding number of seconds (s) per hour (hr). Therefore:

$2{,}016\ W.h\ x\ (60\ x\ 60)\ s\ per\ hr = 7.26\ x\ 10^{6}\ J$