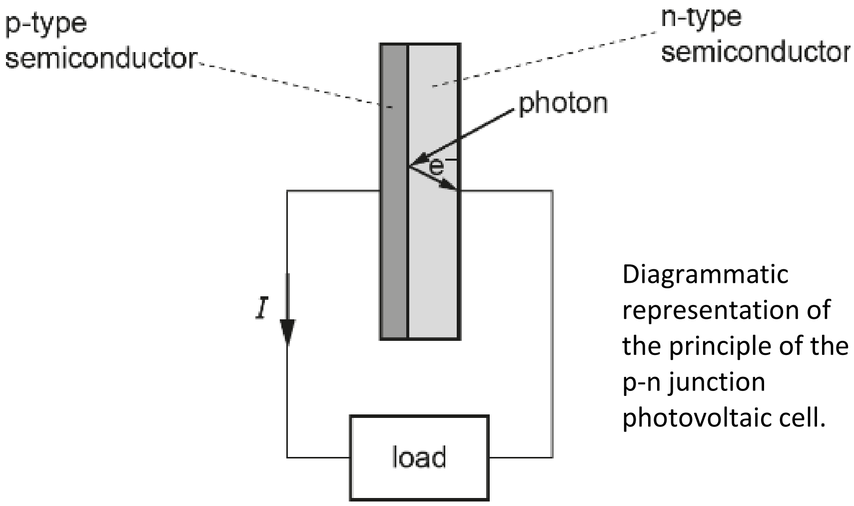
A **Level** Physics B H557/02 - Advance Notice Article 2018

Flying on sunshine

Having left the Earth nearly five years earlier, the space probe Juno entered orbit around Jupiter on July 4, 2016. A little over three weeks later, on July 26, the aeroplane Solar Impulse 2 landed in Abu Dhabi having flown around the world in a number of stages. Juno and Solar Impulse 2, both record-breakers, share a common power source – the Sun. Juno has travelled further from the Sun than any previous solar-powered probe and Solar Impulse 2 is the first solar-powered aeroplane to circle the globe. These achievements show that there is much more to solar cells than simply units for recharging batteries to power calculators or LED garden lights. Banks of solar cells are increasingly seen on the roofs of houses, factories and schools and missions such as Juno and Solar Impulse 2 help push forward the technology of solar power, improving its efficiency and making sunshine an increasingly attractive source of energy.

Photovoltaic cells

When light of sufficiently high frequency strikes a metal surface, photoelectrons are released. This is the photoelectric effect, explained by Einstein in 1905. In modern terminology, a photon transfers its energy to an individual electron which, if the energy of the photon is great enough, will escape the surface of the metal.



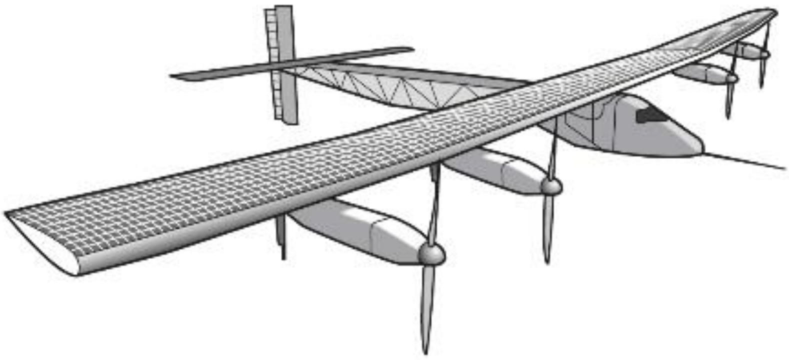
Diagrammatic representation of the principle of the p-n junction photovoltaic cell.

Photovoltaic cells (or solar cells) also rely on the transfer of energy from a photon to an electron. In this case, photons strike electrons within a semiconductor arrangement known as a p-n junction, a p-type semiconductor joined to an n-type semiconductor. The details of the physics of the junction are beyond the scope of this article. If photons striking the cell have sufficient energy, electrons will be promoted into the ‘n’ region. This sets up an e.m.f. which can drive a current through a load. If the wavelength of light falling on the semiconductor is too long there will be no e.m.f. generated.

The photovoltaic cell is a slice of p-n material. Its upper surface (the top of the n-type layer) has a grid of wires to collect the electrons which pass through the load and then back to the p-type layer. The upper surface can also be given a non-reflective coating to increase the efficiency of the cell. An individual cell can produce an e.m.f. of about 0.5 V. Combining a number of cells in series increases the e.m.f. of the system. Typically, a number of cells are combined in a module which produces an e.m.f. of 12 V. Such modules can be combined to produce e.m.f.s and currents suitable for a range of applications. In nearly all cases, the cells are used to recharge batteries to provide a constant source of power independent of light levels.

Solar Impulse 2

A solar-powered aircraft needs to be light and have a large surface area of wing for gliding and to provide a surface for the solar cells. The skin of the wings is supported by an internal frame made from carbon fibre which is low density, stiff and strong. The plane does not fly at a constant height; during daylight, when there is sufficient light to power the motors and recharge the batteries, it rises to a height of 8500 m. At night it glides down to a height of about 1500 m over a period of 4 hours. After this, the motors are powered by the batteries until the cycle repeats the next day.



Solar Impulse 2 Data
Number of solar cells: 17 000
Total area of solar cells: 270 m^2
Mass of batteries: 630 kg
Energy storage in batteries:
9.4×10^5 J kg^{-1}
Total mass of plane: 2300 kg
Efficiency of solar cells: 23%
Wingspan: 72 m

Juno

The Atlas V rocket that launched Juno did not give the spacecraft sufficient energy to climb the gravitational potential well from Earth to Jupiter. To gain more energy, after orbiting the Sun for two years, Juno swung past the Earth, picked up kinetic energy from the planet and headed out for Jupiter. This is a process known as a gravitational slingshot. Simplifying the situation greatly, imagine the situation shown in Fig. 3, where V_S is the velocity of the spacecraft relative to the Sun and V_E is the velocity of the Earth relative to the Sun.

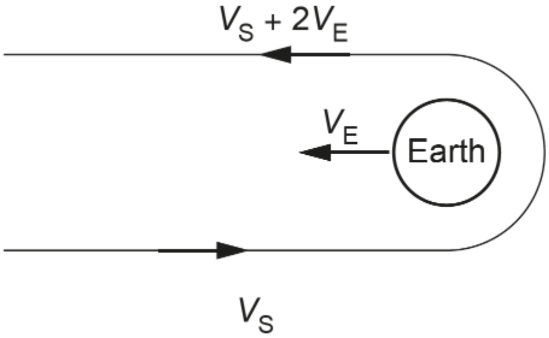
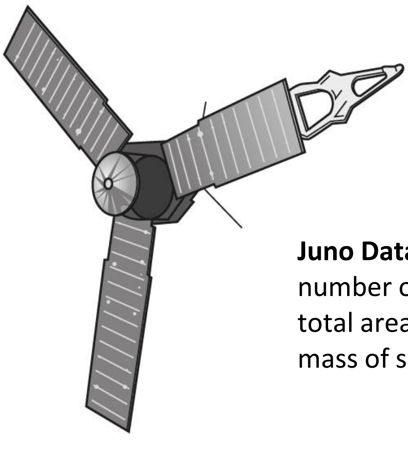


Fig. 3 Velocities of approach and recession of spacecraft to Earth, relative to the Sun.

From the point of view of an observer on the Earth, the spacecraft approaches at velocity $V_S + V_E$. The spacecraft swings past the Earth and leaves at the same speed relative to the Earth that it approached. But relative to the Sun things look rather different; its initial velocity is V_S and when the spacecraft is travelling away with a velocity $V_S + V_E$ relative to the Earth it will be travelling relative to the Sun at velocity $(V_S + V_E) + V_E = V_S + 2V_E$. Of course, spacecraft do not make head-on approaches to planets in this manner but this simplification shows the basic principle. When Juno performed the slingshot manoeuvre with the Earth, it increased its speed from 3.5×10^4 m s^{-1} to 4.2×10^4 m s^{-1}.

The intensity of solar radiation follows an inverse-square relationship with distance from the Sun. Jupiter is 5.2 astronomical units (AU) from the Sun; in other words, 5.2 times further from the Sun than the Earth is. The solar panels on Juno need to be as large and efficient as practicable. Powered only by the Sun, Juno will orbit Jupiter while sending valuable scientific data back to Earth. It is expected to make about 50 orbits of the planet until its instruments and solar cells are too damaged by radiation to be of further use and the spacecraft will be directed to fall towards Jupiter, burning up in the atmosphere of the giant planet. Juno and Solar Impulse 2 show that solar cells have a bright future – even in the darker reaches of the Solar System.



Juno Data
number of solar cells: 19 000
total area of solar cells: 60 m^2
mass of spacecraft: 3600 kg