# A level Physics B

H557/02 Scientific literacy in physics

Question Set 20 Section C

This question set is based on the **Advance Notice** article from **June 2018** (included in this document – see 'Resource Materials')

1 **(a)** **(i)** In 1905, Einstein explained the photoelectric effect using the equation

maximum kinetic energy photoelectrons emitted from a surface = $hf - \varphi$

where h is the Planck constant, f is the frequency of light incident on the surface and φ is the work function of the surface. **Fig. 1.1** shows this relationship for the metal rubidium.
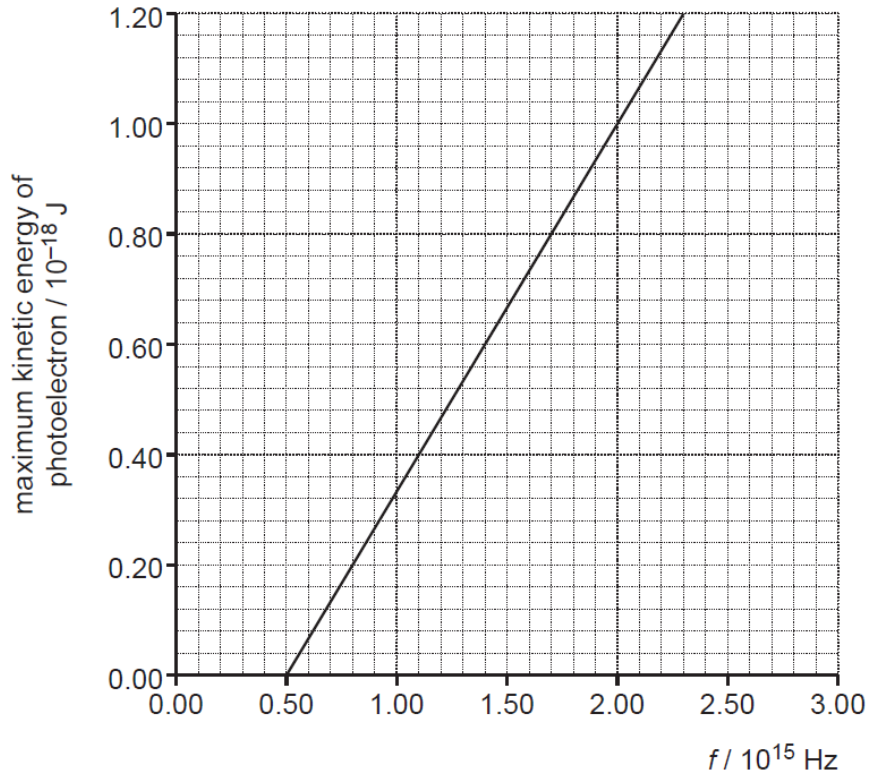
Fig.1.1

Use the graph in **Fig. 1.1** to find the work function of the metal.

work function =……………………..……………..……….J **[2]**

(ii) Explain the meaning of the term *work function* and explain why Einstein's equation gives the **maximum** kinetic energy of the electrons emitted for a particular frequency of incident light (lines 14 – 17 in the Article). **[2]**

(b) Add a second line to the graph of **Fig. 1.1** for a metal surface with a work function which is double that of the work function for rubidium. **[2]**

2*   The upper surface of a solar cell is represented in **Fig. 2.1**.

Use ideas about superposition of waves to explain why a transparent layer of silicon monoxide about 100 nm thick reduces the amount of reflection of light of wavelength 613 nm and increases the efficiency of the solar cell (lines 29 – 30 in the Article).
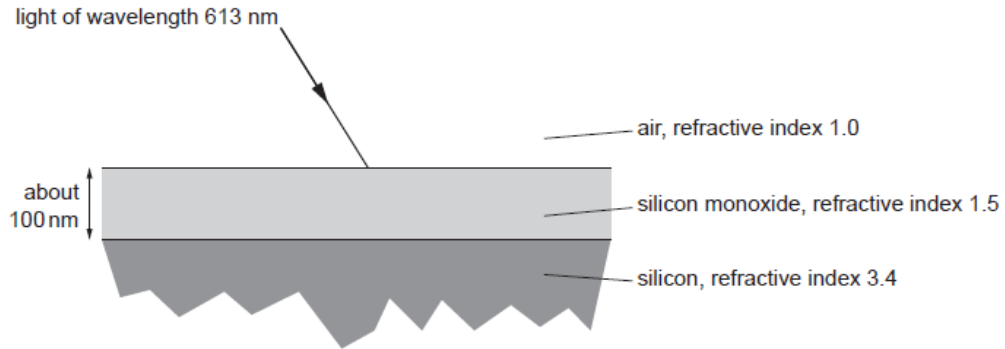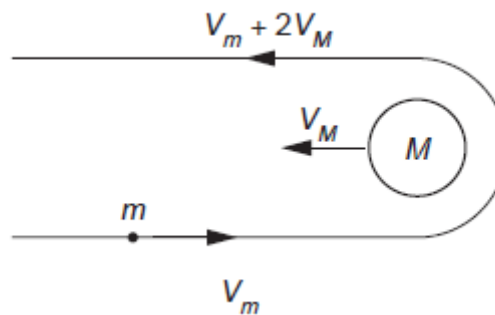

Fig. 2.1   **[6]**

3   This question is about the effect of the gravitational slingshot on the motion of the Juno spaceprobe (lines 45 – 57 in the Article).

Fig. 3.1 shows a simplified situation in which a space probe of mass m sweeps around a planet of mass M.

Fig. 3.1

(a)   Show that the change in momentum of the space probe $= 2\,m\,(V_m + V_M)$.   **[2]**

(b)   The planet has a much greater mass than the space probe. Use the principle of conservation of momentum to describe the effect that the slingshot will have on the motion of the planet.   **[2]**

(c)   Use the data below to show that the Juno probe has sufficient energy per kg to move from 1AU to 5.2AU after its gravitational slingshot (see lines 58 – 60 in the Article).

      mass of Sun $= 2.0 \times 10^{30}$ kg
      1 AU $= 1.5 \times 10^{11}$ m
      velocity of Juno after slingshot $= 4.2 \times 10^4$ m s^{-1}

         [4]

4   Solar Impulse 2 recharges its batteries during the day as it climbs from 1500 m to 8500 m. The solar cells produce an output power of 62.1 kW.

Use data from page 3 of the Article to show that the energy produced by the solar cells over eight hours of daylight is sufficient to lift the plane from 1500 m to 8500 m and fully recharge the batteries.

Make your reasoning clear.   **[4]**

5   The intensity of solar radiation at 1AU from the Sun is $1.4 \, kW \, m^{-2}$. At a distance of 5.2AU from the Sun, the solar cells on the Juno probe produce a power of 500 W. Use data from page 4 of the Article to calculate an estimate of the efficiency of the solar cells.

efficiency =……………………….……….……….……….……….…%   **[3]**

Total Marks for Question Set 20: 27

Resource Materials

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,
5   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
10   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.
15   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.

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
20   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.
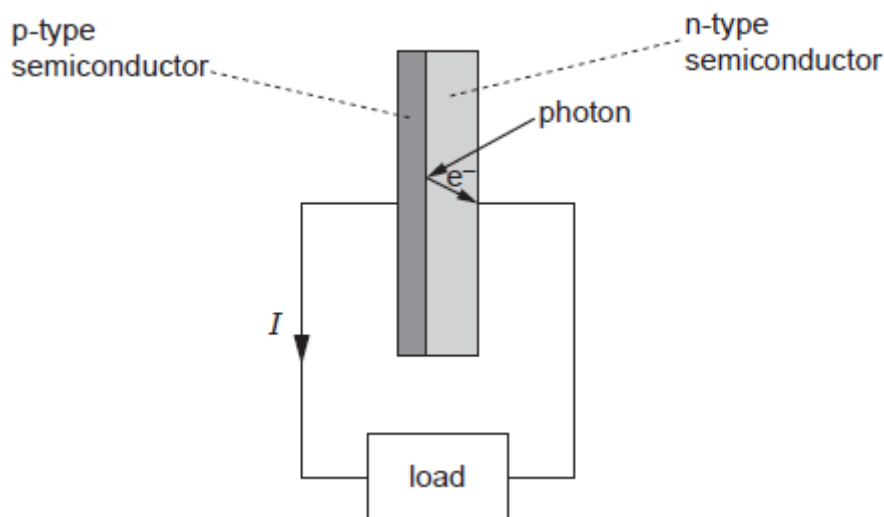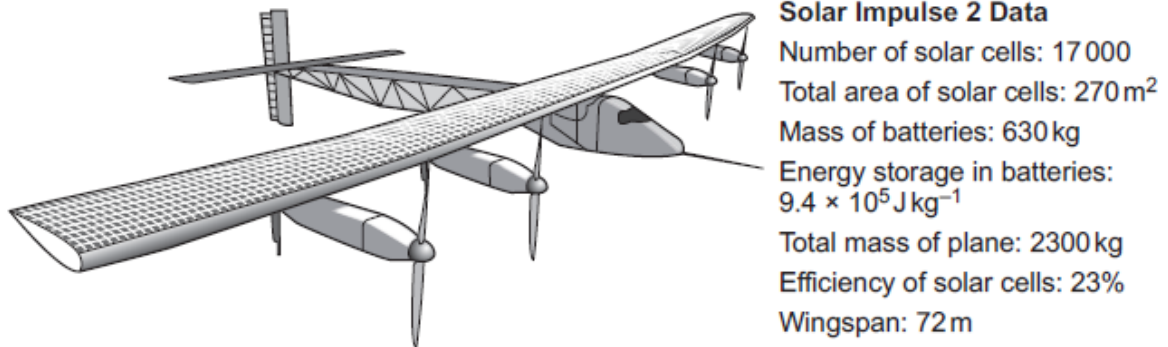

25   **Fig. 1**
Diagrammatic representation of the principle of the p-n junction photovoltaic cell. The photovoltaic cell is a slice of p-n material. Its upper surface (the top of the n-type layer) has a grid of wires to collect the electrons which pass through the load and then back to the p-type layer. The upper surface can also be given a non-reflective coating to increase the efficiency of the cell. An
30   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.

35 **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.


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

Fig. 2 Solar Impulse 2

40 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.

Juno

45 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
50 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.
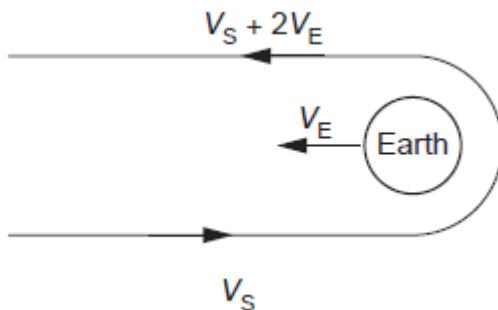
Fig. 3 Velocities of approach and recession of spacecraft to Earth, relative to the Sun.

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
55 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
60 Earth, it increased its speed from $3.5 \times 10^4 \, \mathrm{m\,s^{-1}}$ to $4.2 \times 10^4 \, \mathrm{m\,s^{-1}}$.
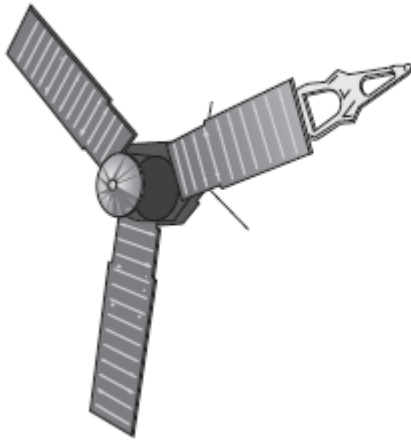
Juno Data

number of solar cells: 19 000

total area of solar cells: $60 \, \mathrm{m^2}$

mass of spacecraft: 3600 kg

Fig. 4 Juno's three solar-cell arrays.

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.
65 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
70 of the Solar System.