OCR
Oxford Cambridge and RSA

A level Physics B

H557/02 Scientific literacy in physics

Question Set 21 Section C

This question set is based on the **Advance Notice** article from **June 2019** (included in this document – see 'Resource Materials')

1 **Fig. 1.1** is an image from Mariner 9. It shows most of the crater at the top of Olympus Mons.

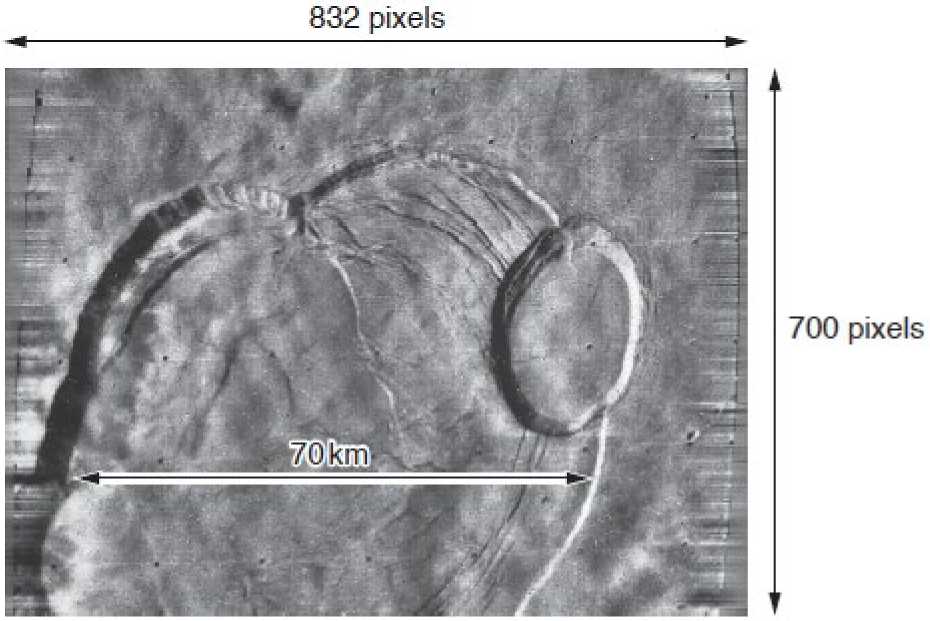


Fig. 1.1

Use data from **Fig. 1.1** to calculate the resolution of the image.

resolution = ……………………………………… km pixel^{-1} **[2]**

2 (a) This question is about Martian meteorites (lines 43–47).

Use the value of G and data from the article (lines 56–62) to show that the radius of Mars is about 3.4×10^6 m.

[2]

(b)* Calculate the gravitational potential at the surface of Mars and use this value to estimate the energy needed to eject a 0.2 kg rock from the surface to a great distance from the planet. Explain your reasoning.

Use ideas about the gravitational potential of the Sun and the Earth to explain why your calculated value is higher than the energy required for the rock to reach Earth but lower than the value required for the rock to escape from the Solar System. **[6]**

3 An estimate of the atmospheric pressure p at height h above the surface of Mars can be found from the equation

$$\ln p = \ln p_s - \frac{mgh}{kT}$$

where p_s is the pressure at the average surface level, g is the gravitational field strength at the surface, k the Boltzmann constant and T the temperature of the atmosphere.

The pressure at the top of Olympus Mons is 0.03 kPa. Assuming that the Martian atmosphere is carbon dioxide (mass of one molecule = 7.3×10^{-26} kg), use the equation given and data from the article (lines 56–62) to calculate an estimate for the height of Olympus Mons above average surface level.

Suggest **one** reason why this method of estimating the height may be unreliable and explain how this would affect the value of the pressure at the top of Olympus Mons.

Calculation:

height =………………………………………… m

Suggestion and explanation:

[4]

4 A large proportion of the radiation absorbed by astronauts comes from high-energy protons in cosmic rays. The American space agency, NASA, estimates that the dose equivalent received by an astronaut on a three-year return trip to Mars is about 1200 mSv. The calculation assumes that the astronaut spends 18 months on the surface of the planet.

(a) The risk of contracting cancer due to radiation exposure is 5% per sievert. The percentage risk of contracting cancer for an astronaut on a three-year mission to Mars is about 6%. Compare this with the risk for someone on Earth over the same period. Give reasons for the difference in risk on the two planets.

Annual dose equivalent on Earth from cosmic rays = 0.4 mSv.

risk on Earth =……………………………………… %

[3]

(b) Explain why exposure to radiation increases the risk of contracting cancer and how the high level of radiation on the surface of Mars may affect the design of the buildings for a human colony on the planet.

[2]

5 This question is about placing a 'magnetic shield' at the L1 point between Mars and the Sun (lines 86–95). **Fig. 5.1** shows the position of the L1 point.

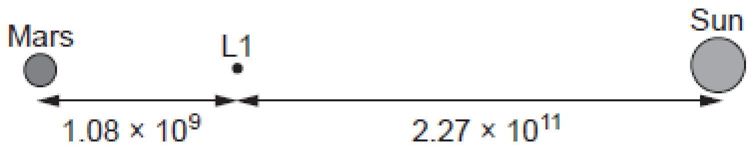


Fig. 5.1 (not to scale)

(a) Calculate the centripetal force required to keep a 1000 kg 'shield' in orbit around the Sun at the L1 point with an orbital period the same as the orbital period of Mars.

Show that the combined gravitational force from the Sun and Mars acting on the 'shield' is approximately equal to the centripetal force required.

orbital period of Mars = 5.94×10^{7} s
mass of Sun = 2.00×10^{30} kg

[5]

(b) Suggest why the shield may not remain at the L1 point even though the net force from Mars and the Sun is equal to the centripetal force required.

[1]

Total Marks for Question Set 21: 25

Resource Materials

Is there Life on Mars?

Observations from Earth

The planet Mars appears as a red star-like object to the unaided eye. Its reddish colour encouraged the Romans to name the planet after their god of war and, since then, Mars has caught the imagination of astronomers and writers alike.

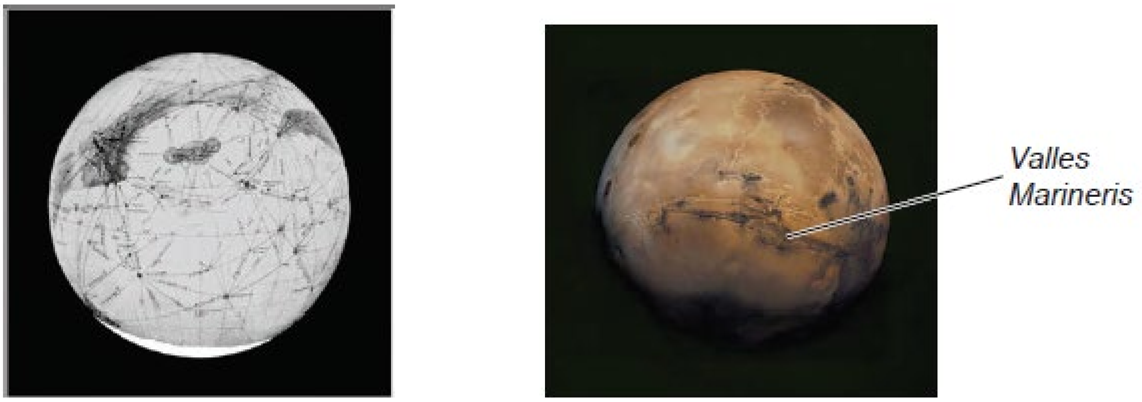
Mars does not take a simple path through the skies that the ancient observers could easily explain using their model of an Earth-centred Universe with the Sun, Moon, planets and stars revolving around a stationary Earth. It took the genius of Johannes Kepler in the early decades of the seventeenth century to provide a simple explanation for Mars's reversals of direction inits journey through the constellations. Kepler reasoned that the planets, including Earth, travel around the Sun in ellipses and that the square of the orbital period of a planet is proportional to the cube of its mean distance from the Sun. Kepler's laws, an explanation for the puzzling behaviour of Mars, gave a new perspective on the Universe which Isaac Newton embraced in his theory of universal gravitation published in 1687.

Visual observations of the planets improved as telescopic astronomy developed, but some observers recorded details that have since proved to be illusions. In 1877, the Italian Giovanni Schiaparelli used favourable observing conditions to draw a map of Mars. He observed what he called *canali*, translated as canals, on the surface of Mars. This apparent observation was interpreted as evidence of liquid water on the planet.

Some other observers reported similar features. The American astronomer Percival Lowell made detailed drawings and believed that canals were made by intelligent beings in an attempt to transport water from the poles of the planet to the barren equatorial regions. Many astronomers were sceptical about Lowell's claims because of the limited resolution of the telescopes of the time but his ideas caught the popular imagination. For example, H.G. Wells took Lowell's idea of a dying Mars and imagined its inhabitants attempting to colonise the Earth in his 1897 novel *The War of the Worlds*.

A closer look

In 1971, Mariner 9 became the first space probe to orbit Mars and it succeeded in sending images back to Earth of a barren landscape that showed signs of water flow in the distant past but no evidence of liquid water on the surface. However, Mariner revealed that Mars has a dramatic geological past that produced, among many other features, a huge system of canyons, the *Valles Marineris*, which cuts across 4000 km of the surface of the planet, reaching depths of 7 km. This can be seen in the right-hand image of Fig. 1. Mariner 9 also discovered the largest volcano in the Solar System, Olympus Mons, with a crater 80 km wide and standing about 27 km above the average surface height.



Map by Lowell's team (left) and an image from the Viking 1 orbiter (1976)

Fig. 1

Mariner was followed by the Viking 1 lander, which touched down on the surface of Mars in 1976. One of the purposes of the mission was to search for evidence for simple life on the planet. Viking found no such evidence and data from more recent landers suggests that Mars is unlikely to have ever supported even the simplest life form.

Visitors from Mars

The Earth is frequently struck by small fragments of rocky material. Some of these are known to have originated on Mars. It is thought that a collision between the planet and an asteroid or comet could give the fragments sufficient energy to escape Mars. Some scientists think that there is fossil evidence of possible simple life forms in samples of the Martian meteorites, but thisis disputed.

Visitors to Mars

Recent years have seen a growing interest in human missions to Mars. Perhaps, rather than the terrifying machines of *The War of the Worlds* colonising Earth from a failing planet, humans will colonise Mars from an overcrowded, resource-hungry world. It is known that there is sufficient water-ice on and under the planet for a colony to be set up and Mars has many minerals vital to maintaining such a venture. However, there are numerous practical problems to overcome because Mars is a very different world from Earth. Colonising Mars is a technical and scientific challenge that dwarfs any other attempted by humankind.

Mars data: gravitational field strength at surface = 3.7 N kg^{-1}
mass = 6.4 × 10^{23} kg
average surface temperature = 210 K
atmospheric pressure at surface = 0.6 kPa
orbital radius = 2.3 × 10^{11} m

Atmosphere: 95% carbon dioxide, 3% nitrogen, remaining fraction composed of argon and trace amounts of other gases

The small size of Mars means that it has kept little of any atmosphere it may have once had. The Earth's atmosphere is protected from a large proportion of cosmic rays and other charged particles by its magnetic field, producing a magnetic barrier around the Earth known as the magnetosphere. Although Mars had a magnetic field in earlier times, it now has no such field and a greater proportion of charged particles from the Sun reach the surface of the planet, giving a higher intensity of radiation and increasing the rate of loss of atmosphere. The low pressure on the surface of Mars means that humans will be required to wear pressure suits when outside their pressurised cabins. The dangers from radiation will limit time spent outside living quarters, which will need to be carefully designed and located. Such buildings require materials and energy to construct. If the materials are not transported from Earth, the early missions to the planet will need to seek the minerals required and set up production plants. Some energy will be available from sunlight, but the inverse-square law shows that the available energy will be lower than that at Earth.

Terraforming Mars

An even more ambitious plan than setting up colonies on Mars and protecting the new Martians from their hostile environment is to change the environment to suit humans, a process known as *terraforming*. Two major challenges faced are: (a) to increase the amount of carbon dioxide in the atmosphere to produce global warming and (b) to create a magnetosphere to reduce the intensity of radiation at the surface and slow down the loss of the new gases pumped into the atmosphere. Mars has sufficient carbon dioxide as dry ice in its polar regions to significantly increase the atmospheric pressure. One suggestion is to use orbiting mirrors to focus sunlight on the polar regions to release gaseous carbon dioxide. If sufficient carbon dioxide is introduced into the atmosphere, liquid water will remain on the surface rather than rapidly evaporating.

Pumping more gas into the atmosphere will not be worthwhile if cosmic rays are allowed to strip the atmosphere away. It has been suggested that a magnetic shield might be placed between the Sun and Mars to direct cosmic rays away from the planet in a similar fashion to the magnetosphere around Earth.

The idea is that the shield is placed at the 'L1' point between Mars and the Sun (Fig. 2). At this position, the shield will orbit the Sun at the same rate as Mars so the shield, Mars and the Sun will remain in line. The gravitational pull of Mars reduces the centripetally acting gravitational force on the shield from the Sun as the force due to Mars acts in the opposite direction to that of the Sun. The values of the forces due to Mars and the Sun give a net force on the shield that is precisely that required to orbit the Sun at the same rate as Mars, even though it is nearer the Sun.

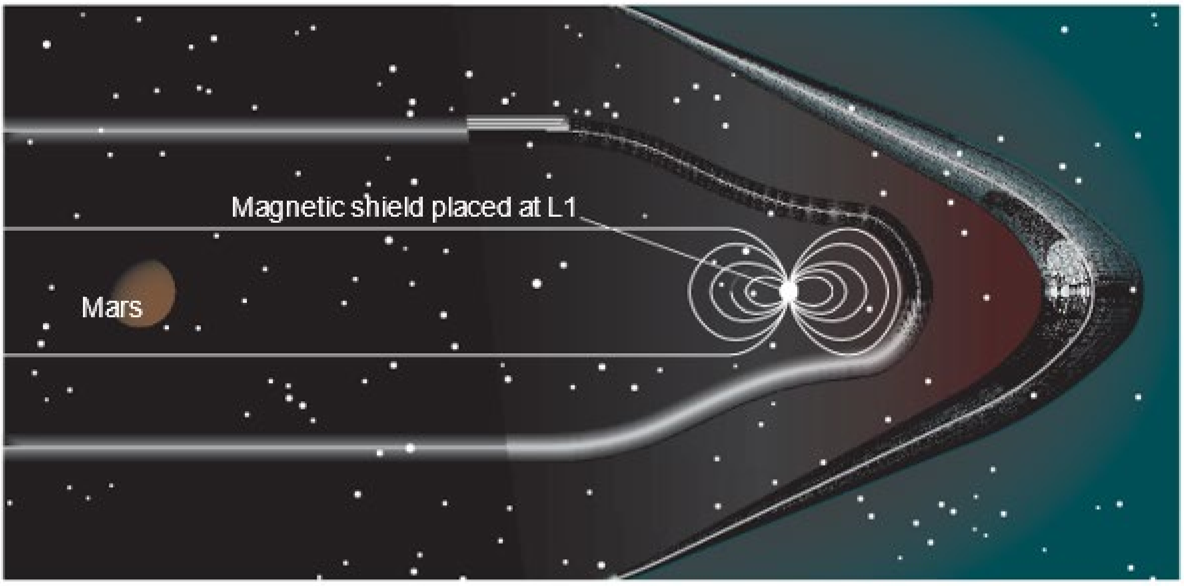


Fig. 2

Many scientists and engineers are working on developing technologies and systems to allow humans to reach Mars, and possibly stay on the surface of the planet. NASA has recently stated that it hopes to have humans on the surface in the 2030s and Russia has made a similar statement of intent. Private companies are also investigating missions to the red planet. Perhaps the answer to David Bowie's question 'Is there life on Mars?' is: not at the moment, but in a few decades' time, who knows?