H557/02/AN : SA's Questions 2019 v1.0

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- Derivation of Kepler's 3rd Law
- Inverse Square Law - data test

Data Given in Article

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	

Additional Data

- **Data, Formulae and Relationships Booklet**
- Radius of Mars = 3390 km
- Mars image is 500 × 500 pixels and 24 bits per pixel
- Molar mass of carbon dioxide = 4.40×10^{-2} kg mol^{-1}
- Molar mass of nitrogen = 2.80×10^{-2} kg mol^{-1}

Questions

1) On which album does Bowie's Life on Mars appear?

2) a) Show that, with a surface gravity of 3.7 N kg^{-1} and a mass of 6.4×10^{23} kg, Mars has a radius of about 3400 km
   b) Calculate the gravitational potential at the surface of Mars taking the radius to be 3390 km
   c) Calculate the Gravitational Potential Energy needed to lift a 2500 kg Mars lander back into orbit at 280 km
   d) Calculate the Kinetic Energy needed to lift a 2500 kg Mars lander back into orbit at 280km
   e) Calculate the total energy needed to reach orbit and the percentage that is kinetic and gravitational.
   f) A day on Mars is 24 hours 40 minutes. Show that the altitude of an areostationary orbit is about 17000 km.

3) Assuming the image of Mars is 500 x 500 pixels at 24 bit per pixel.
   a) Calculate the resolution of the image.
   b) Calculate the amount of information in the image.
   c) Calculate the number of alternative colours that the Image can contain.
   d) Calculate the data transfer rate needed to transmit the image in 2 ½ minutes.
   e) Describe how each of the following image processing techniques could improve the image of mars:
   i) vary brightness ii) vary contrast iii) reduce noise iv) detect edges v) false colour

4) The orbital radius of Mars's orbit is 2.3×10^{11} m and that of the Earth is 1.5×10^{11} m
   a) Use Kepler's 3rd law $T^2 \propto r^3$ to show that the time for Mars to orbit the Sun is about 687 Earth days.
   b) Calculate i) the orbital velocity and ii) the centripetal acceleration due to Mars's orbit around the Sun.
   c) Calculate the maximum and minimum times for a radio signal to travel from Earth to Mars and back.

5) The mean surface temperature on Mars is 210 K

a) Show that the root mean square speed of a gas molecule of mass m is given by $c_{rms} = \sqrt{\frac{3kT}{m}}$

b) Calculate the root mean square speed of i) CO_2 molecules ii) N_2 molecules

c) Show that the escape velocity for a gas molecule at the surface of a planet is given by: $v_{esc} = \sqrt{\frac{2GM}{r}}$

d) Calculate the escape velocity for Mars.

e) Comment on the significance of the values for your answers to b) and d)

6) a) Use the Boltzmann factor to calculate the ratio of $N_2 : CO_2$ molecules with that have enough kinetic energy to escape from Mars's gravity at the mean surface temperature of 210 K. What can you conclude from your answer?

b) By considering the energy required to move a gas molecule to a height h above the surface of a planet use the Boltzmann factor to show that $p = p_0\, e^{\left(\frac{-mgh}{kT}\right)}$
where p_0 is the surface pressure, p is the pressure at height h.

c) Calculate the pressure at the top of Mars's largest extinct volcano Olympus Mons which it at a height of 22 km. You can assume that Mars's atmosphere is 100% CO_2

7) The background radiation level at the surface of Mars is on average 80 mSv per year although it can reach as high as 20 mSv in one day during a solar proton event. A dose equlivent of 1 Sv gives a probability of developing cancer of 3% in an individual.

a) Calculate the risk of developing cancer due to a single solar proton event.
b) If a colony of 500 individuals were to be established on Mars calculate an estimate of how many would be expected to develop a radiation induced cancer after a 20 year period on Mars.

8) The distance from Mars to its L1 point is 320 times the radius of Mars.
Solar protons can have energies up to 10 keV

a) Calculate the speed of 10 keV solar protons
b) Calculate the maximum angle through which solar protons must be deflected at L1 in order to miss Mars.
c) Calculate the distance that a 10 keV solar proton would have to travel in a 2.0 μT uniform magnetic field at L1 in order to be deflected by enough to miss Mars.