Edexcel A2 Physics: Space – Calculation Practice

Praneel Physics

1. Calculate the gravitational force between two masses of 5 kg and 10 kg separated by a distance of 2 m. Use $G = 6.67 \times 10^{-11}$ N m^2/kg^2. **(P)**

Working and Answer:
Using Newton's law of gravitation: $F = G\frac{m_1 m_2}{r^2}, F = 6.67 \times 10^{-11}\frac{5 \times 10}{2^2} = 8.34 \times 10^{-11}$ N.

2. A satellite orbits the Earth at a height of 300 km. Calculate the gravitational potential energy of a 1000 kg satellite at this height. Use $g = 9.81\,\text{m/s}^2$. **(P)**

Working and Answer:
Gravitational potential energy: $U = mgh, U = 1000 \times 9.81 \times 300000 = 2.943 \times 10^9$ J.

3. If a comet travels at a speed of 50 km/s and has a mass of 10^{12} kg, calculate its kinetic energy. **(P)**

Working and Answer:
Kinetic energy: $KE = \frac{1}{2}mv^2, KE = \frac{1}{2} \times 10^{12} \times (50000)^2 = 1.25 \times 10^{22}$ J.

4. Calculate the escape velocity from the surface of Mars, which has a radius of 3.4×10^6 m and a mass of 6.42×10^{23} kg. **(P)**

Working and Answer:

Escape velocity: $v_e = \sqrt{\frac{2GM}{r}}, v_e = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 6.42 \times 10^{23}}{3.4 \times 10^6}} \approx 5027\,\text{m/s}$.

5. A planet has a mass of 5.97×10^{24} kg and a radius of 6.37×10^6 m. Calculate the gravitational field strength at its surface. **(P)**

Working and Answer:

Gravitational field strength: $g = \frac{GM}{r^2}, g = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(6.37 \times 10^6)^2} \approx 9.81\,\text{m/s}^2$.

6. A spacecraft travels from Earth to Mars, covering a distance of 225 million km in 300 days. Calculate its average speed in m/s. **(PP)**

Working and Answer:
Average speed: $v = \frac{d}{t}, d = 225 \times 10^6 \times 1000\,\text{m}, t = 300 \times 24 \times 3600\,\text{s}, v = \frac{225 \times 10^9}{300 \times 86400} \approx 8.70\,\text{m/s}.$

7. A star emits light with a wavelength of 500 nm. Calculate the frequency of this light. **(PP)**

Working and Answer:
Using the equation: $c = \lambda f, f = \frac{c}{\lambda} = \frac{3 \times 10^8}{500 \times 10^{-9}} = 6 \times 10^{14}\,\text{Hz}.$

8. If the distance from the Earth to the Sun is approximately $1.5 \times 10^{11}\,\text{m}$, calculate the time it takes for light to travel this distance. **(PP)**

Working and Answer:
Time: $t = \dfrac{d}{v}, t = \dfrac{1.5 \times 10^{11}}{3 \times 10^{8}} = 500\,\text{s}.$

9. A black hole has a mass of $10^{30}\,\text{kg}$. Calculate the Schwarzschild radius of the black hole. **(PP)**

Working and Answer:
Schwarzschild radius: $r_s = \dfrac{2GM}{c^2}, r_s = \dfrac{2 \times 6.67 \times 10^{-11} \times 10^{30}}{(3 \times 10^{8})^2} \approx 2950\,\text{m}.$

10. Calculate the gravitational potential energy of a 2000 kg satellite at an altitude of 400 km above the Earth's surface. **(PP)**

Working and Answer:

Using $U = -\dfrac{GMm}{r}, r = R + h = 6.37 \times 10^6 + 400 \times 10^3, U = -\dfrac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 2000}{r} \approx -7.94 \times 10^{10}$ J.

11. A planet orbits a star with a period of 365 days and an average distance of 1.5×10^{11} m. Calculate the mass of the star. **(PPP)**

Working and Answer:
Using Kepler's third law: $T^2 = \frac{4\pi^2}{GM}a^3, M = \frac{4\pi^2 a^3}{GT^2}, T = 365 \times 24 \times 3600\,\text{s}$, $a = 1.5 \times 10^{11}\,\text{m}, M \approx 1.99 \times 10^{30}\,\text{kg}$.

12. A spacecraft travels at a speed of $0.8c$ (where c is the speed of light). Calculate its relativistic mass if its rest mass is 1000 kg. **(PPP)**

Working and Answer:
Relativistic mass: $m = \frac{m_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}, m = \frac{1000}{\sqrt{1 - (0.8)^2}} \approx 1000/0.6 \approx 1667\,\text{kg}$.

13. Calculate the gravitational force acting on a 1000 kg satellite in a circular orbit at a height of 500 km above the Earth's surface. **(PPP)**

Working and Answer:
Using $F = \dfrac{GMm}{r^2}, r = R + h = 6.37 \times 10^6 + 500 \times 10^3, F = \dfrac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1000}{(r)^2} \approx 9.81\,\text{N}.$

14. A star is moving away from Earth at a speed of 3000 km/s. Calculate the redshift of the light emitted from this star. **(PPP)**

Working and Answer:
Redshift: $z = \dfrac{v}{c}, z = \dfrac{3000 \times 10^3}{3 \times 10^8} = 0.01.$

15. A planet has a radius of 7×10^6 m and a mass of 8×10^{24} kg. Calculate the gravitational potential at a distance of 2×10^7 m from the center of the planet. **(PPP)**

Working and Answer:

Gravitational potential: $U = -\frac{GM}{r}, U = -\frac{6.67 \times 10^{-11} \times 8 \times 10^{24}}{2 \times 10^7} \approx -2.67 \times 10^9$ J/kg.

16. A spacecraft is traveling to a distant star that is 4.2 light years away. If it travels at $0.9c$, calculate the time taken to reach the star as measured by the spacecraft. **(PPPP)**

Working and Answer:

Time dilation: $t' = \dfrac{t}{\sqrt{1-\left(\frac{v}{c}\right)^2}}, t = \dfrac{4.2 \times 9.461 \times 10^{15}}{0.9 \times 3 \times 10^8} \approx 1.56 \times 10^8\,\text{s}, t' = \dfrac{1.56 \times 10^8}{\sqrt{1-(0.9)^2}} \approx 1.56 \times 10^8/0.436 \approx 3.58 \times 10^8\,\text{s}.$

17. Calculate the luminosity of a star that has a surface temperature of 6000 K and a radius of 1.5×10^6 m. Use the Stefan-Boltzmann law. **(PPPP)**

Working and Answer:
Luminosity: $L = 4\pi R^2 \sigma T^4, L = 4\pi(1.5 \times 10^6)^2(5.67 \times 10^{-8})(6000)^4 \approx 3.84 \times 10^{26}$ W.

18. A neutron star has a mass of 2×10^{30} kg and a radius of 10 km. Calculate the gravitational field strength at its surface. **(PPPP)**

Working and Answer:
Gravitational field strength: $g = \dfrac{GM}{r^2}, g = \dfrac{6.67 \times 10^{-11} \times 2 \times 10^{30}}{(10 \times 10^3)^2} \approx 1.34 \times 10^{12}\,\text{m/s}^2$.

19. A galaxy is observed to be moving away from Earth at a speed of 7000 km/s. Calculate the distance to the galaxy using Hubble's law, given that the Hubble constant is 70 km/s/Mpc. **(PPPP)**

Working and Answer:
Using Hubble's law: $v = H_0 d, d = \dfrac{v}{H_0} = \dfrac{7000}{70} = 100\,\text{Mpc}.$

20. Calculate the time it would take for a signal to travel from Earth to a planet 10 light years away. **(PPPP)**

Working and Answer:
Time: $t = 10\,\text{years}.$

21. A star has a mass of 3×10^{30} kg and is located 10 parsecs away from Earth. Calculate the apparent magnitude of the star if its absolute magnitude is 5. **(PPPPP)**

Working and Answer:
Using the distance modulus: $m - M = 5\log_{10}(d) - 5, m = 5 + 5\log_{10}(10) - 5 = 5.$

22. A planet has a mass of 6×10^{24} kg and a radius of 6.4×10^{6} m. Calculate the orbital speed of a satellite in a low orbit at a height of 200 km. **(PPPPP)**

Working and Answer:
Orbital speed: $v = \sqrt{\frac{GM}{r}}, r = R + h = 6.4 \times 10^{6} + 200 \times 10^{3}, v = \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{r}} \approx 7.91\,\text{km/s}.$

23. A star is moving towards Earth at a speed of 5000 km/s. Calculate the blueshift of the light emitted from this star. **(PPPPP)**

Working and Answer:
Blueshift: $z = -\frac{v}{c}, z = -\frac{5000 \times 10^3}{3 \times 10^8} \approx -0.0167.$

24. Calculate the gravitational potential energy of a 1500 kg satellite in a geostationary orbit at an altitude of 35, 786 km above the Earth's surface. **(PPPPP)**

Working and Answer:
Using $U = -\frac{GMm}{r}, r = R + h = 6.37 \times 10^6 + 35.786 \times 10^6, U = -\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1500}{r} \approx -7.07 \times 10^{10}$ J.

25. A star has a luminosity of $10^{30}\,\mathrm{W}$ and is located $100\,\mathrm{pc}$ away. Calculate its apparent brightness. **(PPPPP)**

Working and Answer:
Using the formula: $b = \dfrac{L}{4\pi d^2}, b = \dfrac{10^{30}}{4\pi(100 \times 3.086 \times 10^{16})^2} \approx 2.53 \times 10^{-12}\,\mathrm{W/m^2}$.