Oxford Resources for IB

Physics – 2023 Edition

Answers

Extended response questions – Pages 700–701

Question 1

a. The equation assumes constant acceleration. From the graph, the net force is changing with time hence the acceleration is changing, too.

b. i. The peak force is about 120 N so the maximum acceleration is

$$\frac{F}{m}=\frac{120}{75}=1.6\text{ m s}^{-2}$$

ii. The area under the graph represents the impulse delivered to the bicycle. The area is approximately 24 grid squares, and each grid square is 20 N s. Area = 24 × 20 = 480 N s.

$$m\Delta v=\Delta p\Rightarrow\Delta v=\frac{\Delta p}{m}=\frac{480}{75}=6.4\text{ m s}^{-1}.$$

The final speed of the bicycle is 6.4 m s^{-1}.

c. i. Power output $V \times I$ = 42 × 6.2 = 260 W.

ii. The difference between the emf and the terminal p.d. is equal to the potential drop on the internal resistance *r*.

$$48-42=6.2r\text{, hence }r=\frac{48-42}{6.2}=0.97\ \Omega$$

iii. The increase in the gravitational PE during the entire ride is 75 × 9.8 × 420 = 3.1 × 10^5 J

The rate of change is therefore

$$\frac{3.1\times10^5}{40\times60}=130\text{ W}$$

iv. Useful power output is only 50% of the power transferred from the battery, so there are undesired energy losses. Possible mechanisms include work done against air resistance and other frictional forces, and mechanical inefficiency of the motor and gearing.

d. The gravitational field strength decreases with the square of the distance from the centre of the Earth. The relative change during the ride is

$$\frac{\Delta g}{g}=\frac{\frac{1}{R^2}-\frac{1}{(R+h)^2}}{\frac{1}{R^2}}$$

where R = 6370 km is the radius of the Earth and h = 0.420 km is the gain in height. The calculation gives

$$\frac{\Delta g}{g}=1.3\times10^{-4}=0.013\%$$

The field strength changes by a hundredth of a percent, so by all practical means it can be considered constant.

e. **i.** The work done by the brakes is equal to the change in the kinetic energy of the bicycle:

$$\Delta E_k = \frac{1}{2} \times 75 \times \left(\frac{25}{3.6}\right)^2 = 1.8 \times 10^3 \text{ J}$$

This in turn is equal to the thermal energy transferred to the brakes. The increase in temperature is therefore

$$\Delta T = \frac{\Delta E_k}{mc} = \frac{1.8 \times 10^3}{0.300 \times 850} = 7.1 \text{ K}$$

ii. The calculation assumes that thermal energy accumulates in brakes during deceleration, which is not realistic as brake rotors are moving parts exposed to air and part of the energy will be transferred to the air before the bicycle stops. On the other hand, the rotors are not heated uniformly across their volume and the temperature of the surface in immediate contact with the pads may temporarily rise much more than the calculation suggests.

The solution ignores the work done on the bicycle by other forces, e.g. air resistance or the component of weight parallel to the road, if braking takes part on a slope.

Question 2

a. **i.** Spectral lines are observed when an atom absorbs or emits a photon of energy corresponding to the wavelength of the line, and the energy of the atom changes by the amount equal to the energy of the photon. Since spectral lines have discrete wavelengths, the energy of the atom can only change between a set of specific energy values, known as atomic energy levels.

ii. The photon with the greatest energy is the one with the shortest wavelength, 501.6 nm.

$$E = \frac{hc}{\lambda} = \frac{1.99 \times 10^{-25}}{501.6 \times 10^{-9}} = 3.97 \times 10^{-19} \text{ J}$$

b. **i.** The difference between the emitted and observed wavelength is due to relative motion of the star and the observer on the Earth. The observed wavelength is periodically above and below the laboratory wavelength, so the star periodically moves towards and away from the observer. This can be explained as orbital motion of the star around another body in a binary system.

ii. Use the Doppler effect formula:

$$v = \frac{\Delta\lambda}{\lambda} c = \frac{588.7 - 587.6}{587.6} \times 3 \times 10^8 = 5.6 \times 10^5 \text{ m s}^{-1}$$

c. **i.** The surface temperature is related to the peak wavelength of the black-body spectrum by Wien's displacement law.

$$T = \frac{2.9 \times 10^{-3}}{340 \times 10^{-9}} = 8500 \text{ K}$$

ii. The distance in parsec is the reciprocal of the parallax angle in arc-second:

$$d = \frac{1}{6.5 \times 10^{-3}} = 154 \text{ pc.}$$

Conversion to light years is straightforward: $d = 154 \times 3.26 = 500$ ly

iii. The intensity of radiation coming from the star, as measured on the Earth.

iv. The apparent brightness together with the distance to the star can be used to determine the luminosity L of the star. Since the absolute temperature of the star is known, its total surface area A can be estimated from the Stefan–Boltzmann law, $A = \frac{L}{\sigma T^4}$. Assuming that the star can be modelled as a sphere, its radius can be calculated from the surface area.

d. i. Kepler's laws are a consequence of the law of gravitation and other laws of mechanics. We believe that these fundamental laws are the same throughout the observable Universe, so they allow us to make detailed predictions of the same type as to the orbital motion of planets in other stellar systems.

ii. Kepler's third law, in its generalized form, links three quantities: orbital radius and period of a planet, and the mass of the central star. The radius of the orbit can be determined from this law if, in addition to the orbital period, we have an independent estimate of the mass of the star.

Question 3

a. A collision in which the total mechanical energy of the system is unchanged.

b. i. The momentum gained by stone B is equal but opposite to the change in momentum of stone A. We first calculate the x- and y-components of p, then the magnitude.

$$p_x = 0.10 \times 1.6 - 0.10 \times 1.0 \times \cos 60° = 0.11 \text{ N s}$$

$$p_y = 0.10 \times 1.0 \times \sin 60° = 8.7 \times 10^{-2} \text{ N s}$$

$$p = \sqrt{{p_x}^2 + {p_y}^2} = 0.14 \text{ N s}$$

ii. The change in momentum of the stones is equal to the impulse transferred between them.

$$\text{Force} = \frac{\text{impulse}}{\text{time}} = \frac{0.14}{4.0 \times 10^{-4}} = 350 \text{ N}$$

iii. The kinetic energy lost by stone A is

$$\frac{1}{2} \times 0.10\left(1.6^2 - 1.0^2\right) = 7.8 \times 10^{-2} \text{ J}$$

The kinetic energy gained by stone B is

$$\frac{0.14^2}{2 \times 0.20} = 4.9 \times 10^{-2} \text{ J}$$

which is less than energy change of stone A, hence the collision is not elastic.

c. In the particle model, the incident X-ray photon transfers some of its energy to a recoil electron. The energy of the photon decreases hence the wavelength increases.

d. **i.** We use the Compton scattering equation:

$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos 60°) = 1.2 \times 10^{-12}\ \text{m}$$

ii. The momentum of the electron-photon system is conserved hence the initial momentum of the electron is equal to the change in momentum of the scattered photon, which can be determined if the energy or the wavelength of the photon is known.

iii. The energy of the recoil electron is equal to the energy change of the photon,

$$\frac{hc}{\lambda_i} - \frac{hc}{\lambda_f} = \frac{1.24 \times 10^{-6}}{1.0 \times 10^{-10}} - \frac{1.24 \times 10^{-6}}{1.0 \times 10^{-10} + 1.2 \times 10^{-12}} = 147\ \text{eV}$$

e. **i.** The centripetal force equation is

$$\frac{m_e v^2}{r} = evB$$

Rearranging for *r* gives

$$r = \frac{m_e v}{eB}$$

The speed *v* of the electron can be calculated from the kinetic energy:

$$\frac{1}{2} m_e v^2 = 147 \times 1.6 \times 10^{-19} \Rightarrow v = 7.2 \times 10^6\ \text{m s}^{-1}$$

The radius of the path is

$$r = \frac{9.11 \times 10^{-31} \times 7.2 \times 10^6}{1.6 \times 10^{-19} \times 2.0 \times 10^{-3}} = 2.0\ \text{cm}$$

ii. $$\frac{v}{c} = \frac{7.2 \times 10^6}{3.0 \times 10^8} = 0.024$$

The ratio v/c is much less than one, so the electron's speed is much less than the speed of light. Relativistic effects become important when $v/c > 0.2$.

f. The change in photon's wavelength is constant at a given scattering angle. The wavelength of the incident photon is now shorter, so the same increase in the wavelength in absolute terms corresponds to a greater percentage increase. The proton undergoes a greater relative change in energy, and so a greater percentage of the energy is now transferred to the electron.

g. Radioactive decay can be modelled as repeatedly rolling a large number of dice and removing all dice that land with a particular number upwards. This provides a visual link to an invisible phenomenon and illustrates the random nature of the radioactive decay.

Analogy between gravitational and electric fields allows to apply the results obtained in one area to the other.