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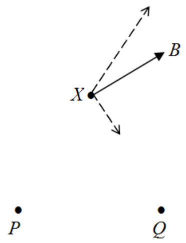
SECTION A

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
B	B	D	D	C	D	C	B	C	D	C	C	C	A	B	D	C	C	B	B

Q1



Q2 Earth radius $= 6370$ km, $\frac{g_{2000}}{g_{1000}} = \left(\frac{d_{1000}}{d_{2000}}\right)^2$, $\frac{g_{2000}}{g_a} = \left(\frac{6370+1000}{6370+2000}\right)^2$, $g_{2000} \approx 0.78 g_a$

Q3

Vertically downward

Q4 Area under the F_g vs r graph $\approx \frac{1}{2}(9.8+2.7)\times 6.37 \approx 40$

Q5 $n = \frac{\sin 45°}{\sin 30°}$, $\sin\theta_c = \frac{1}{n}$.: $\theta_c = 45°$

Q6 Other transmitted rays and internally reflected rays are not shown in the diagram.

Q7 Geostationary satellites have the same speed but not the same velocity.

Q8 The measurement 0.0070 g has a precision of 0.0001 g and an accuracy of 2 (2 significant figures). In comparison it is the most precise and the least accurate.

Q9 $\sqrt{(100\times 9.8)^2 + 200^2} \approx 1000.2$ N

Q10 The Earth attracts the crate (action) and the crate attracts the Earth (reaction).

Q11 (I) is an inertial frame of reference, (II) and (III) are non-inertial.

Q12 Both situations measure the same proper time.

Q13 $20.3 \pm 0.1 = 20.3 \pm 0.5\%$ Area $\approx \frac{1}{2}\times 20.3\times 98.5 \pm (0.5+0.2)\% \approx 999.8 \pm 0.7\% \approx 1000 \pm 7$

Q14 Frequency of vibration $= \frac{338}{2.0} = 169$ s^{-1} and the possible wavelengths (m) are 0.6 (fundamental), 0.3 (first harmonic), 0.2 (second harmonic), … .: possible speeds are approx 101, 51, 34, … m s^{-1}.

Q15 Newton's second law: $\vec{F}_{net} = m\vec{a}$, net force and acceleration are in the same direction.

Q16 All three projectiles have the same change in gravitational potential energy because they have the same change in vertical distance.

Q17 Electric/magnetic fields are perpendicular to the direction of propagation of the electromagnetic wave.

Q18 $\Delta x = \dfrac{\lambda L}{d}$

Q19 Electrons diffract less in an electron microscope because they have shorter wavelength than light in a light microscope.

Q20 Higher intensity increases the number of photons and hence the number of photoelectrons emitted in a unit time.

SECTION B

Question 1

a. $V = nBlv = 10 \times 1.5 \times 0.20 \times 0.50 = 1.5\,\text{V}$

b. $P = \dfrac{V^2}{R} = \dfrac{1.5^2}{0.75} = 3.0\,\text{W}$

c. Magnetic flux into the page increases as the coil moves to the right, inducing a clockwise current in the coil. The current flows from *P* to *Q* through the light globe indicating that *P* and *Q* are positive and negative respectively.

d. As the coil moves to the right, there is a magnetic force $F = nBIL$ on the coil to the left. To keep the coil moving at constant speed $0.50\,\text{m}\,\text{s}^{-1}$, force $F = nBIL$ is required to push the coil to the right.

$F = nBIL = 10 \times 1.5 \times \dfrac{1.5}{0.75} \times 0.20 = 6.0\,\text{N}$

e. $W = P\Delta t = 3.0 \times 1 = 3.0\,\text{J}$ or $W = Fv\Delta t = 6.0 \times 0.50 \times 1 = 3.0\,\text{J}$

Question 2

a.

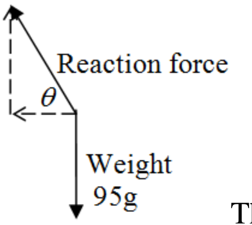
	Side *BC*	Side *AD*
Direction	Into page	Into page
Magnitude	$1.5/0.2 = 7.5$	1

b. Initially, the magnetic force on side *BC* tends to cause a clockwise rotation of the coil and the magnetic force on side *AD* tends to cause the coil to rotate anticlockwise. However, the former is much stronger and the net effect is that the coil starts to rotate clockwise. The combined turning effect of the two forces remains clockwise for rotation $0° < \theta < 90°$ because the force on *BC* is still stronger than that on *AD*. At $90°$ the turning effect of the two forces is momentarily zero because they are aligned. At $90° < \theta < 180°$ the combined turning effect of the two forces is still clockwise because the force on *AD* is now stronger than that on *BC*. The above motion repeats itself every half turn of the coil resulting in a continuous clockwise rotation with increasing speed.

c. The speed of rotation increases initially but the acceleration decreases to zero. Thus the coil will reach a maximum speed of rotation.

Question 3

a. The cyclist must lean at an angle $\theta < 90°$ to provide a reaction force at the same angle θ from the road, consisting of the normal force and a sideway force due to friction towards the centre of the circular corner. The sideway force due to friction helps the cyclist to round the corner.



The diagram shows the forces on the cyclist.

b. Sideway force = centripetal force $= \frac{95 \times 15^2}{20} = 1068.75$ Reaction force $= \sqrt{1068.75^2 + (95 \times 9.8)^2} \approx 1.4 \times 10^3$ N

c. $\tan\theta = \frac{95 \times 9.8}{1068.75}$, $\theta \approx 41°$

d. Same leaning angle: $\tan\theta = \frac{mg}{\frac{mv^2}{r}} = \frac{gr}{v^2}$.: θ does not depend on mass

e. No friction force at $90°$ angle with the road surface .: $\phi° \approx 41°$

Question 4

a. Vertically downward electric field will provide an upward force on the negatively charged particle to counter the force of gravity.

b. Vertically downward magnetic field will provide a horizontal force perpendicular to the horizontal motion of the charged particle.

c. $qE = mg$, $E = \frac{mg}{q} = \frac{(5.0 \times 10^{-8}) \times 9.8}{1.6 \times 10^{-10}} \approx 3.1 \times 10^3$ N C^{-1}

d. $qvB = \frac{mv^2}{r}$, $B = \frac{mv}{qr} = \frac{(5.0 \times 10^{-8}) \times 1.0}{(1.6 \times 10^{-10}) \times 2.0} \approx 1.6 \times 10^2$ T

e. Both $E = \frac{mg}{q} = \left(\frac{m}{q}\right)g$ and $B = \frac{mv}{qr} = \left(\frac{m}{q}\right)\frac{v}{r}$ remain the same when $\frac{m}{q}$, v and r remain the same.

Question 5

a. $F = kx$, $9.8 = k(1.80 - 1.19)$, $k = 16.07$ N m^{-1}

b. $W + \frac{1}{2}k(1.50 - 1.19)^2 = \frac{1}{2}k(1.80 - 1.19)^2$, $W \approx 2.22$ J

c. Length $= 1.80 + 0.30 = 2.10$ m

d. Maximum speed occurs when the band is 1.80 m long as in Figure 1.

$\frac{1}{2} \times 1.00v^2 + \frac{1}{2}k(1.80 - 1.19)^2 + 1.00 \times 9.8 \times 0.30 = \frac{1}{2}k(2.10 - 1.19)^2$, $v \approx 1.20$ m s^{-1}

e. $3.00 = \frac{1}{2}k(1.50 - 1.19)^2 + E_{grav}$, $E_{grav} \approx 2.23$ J

Question 6

a. |Impulse given to the nail| = |change in momentum of the hammer| $= 0.80 \times 1.0 = 0.80\,\text{Ns}$

b. $0.050v = 0.80$, $v = 16\,\text{m s}^{-1}$

c. $F_{av} \times 0.0050 = \frac{1}{2} \times 0.050 \times 16^2$, $F_{av} = 1280 \approx 1.3 \times 10^3\,\text{N}$

d. $F_{av}\Delta t = 0.80$, $\Delta t \approx 6.3 \times 10^{-4}\,\text{s}$

e. If the system consists of the hammer and the nail only **at** impact, total momentum of the system is conserved. After impact the total momentum of the hammer and the nail becomes zero, total momentum of the system is not conserved because the system is not isolated and the momentum is transferred to the wall (the building).
If the system consists of the hammer, the nail and the wall, then the law of conservation of momentum is valid.

Question 7

a. The machinery is operational at minimum 220 V. Current $= \frac{220}{25} = 8.8\,\text{A}$

Maximum voltage drop in the extension cord $= 240 - 220 = 8.8 \times 0.025 \times \ell$.: $\ell \approx 90.9\,\text{m}$

b. Minimum length of extension cord $= 50.0\,\text{m}$.: resistance $= 0.025 \times 50.0 = 1.25\Omega$

Total resistance (cord and machinery) $= 1.25 + 25 = 26.25\Omega$ Current $= \frac{240}{26.25} \approx 9.143\,\text{A}$

Power of machinery $\approx 9.143^2 \times 25 \approx 2090\,\text{W}$; power loss $\approx 9.143^2 \times 1.25 \approx 104\,\text{W}$

c. The double power point has a 15 amp fuse.

When the machinery and the electric kettle are both on, total current through the fuse $\approx 9.143 + \frac{1800}{240} > 15\,\text{A}$

The fuse will blow and cut off the power supply.

Question 8

a. Relative to an Earth bound observer, muons moving at relativistic speed will have their half-lives dilated (longer), allowing them to reach Earth.

b. Relative to an observer travelling with the muons, the distance between Earth and the muons moving at relativistic speed will be contracted, allowing the muons to reach Earth.

Question 9

a. $m = \frac{m_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{9.1 \times 10^{-31}}{\sqrt{1 - 0.8^2}} \approx 1.5 \times 10^{-30}\,\text{kg}$

b. $E_{\text{rest}} = m_0 c^2 = \left(9.1 \times 10^{-31}\right)\left(3.0 \times 10^8\right)^2 \approx 8.2 \times 10^{-14}\,\text{J}$

c. $E_{\text{k}} = E_{\text{total}} - E_{\text{rest}} \approx \left(\frac{1}{\sqrt{1 - 0.8^2}} - 1\right)\left(8.2 \times 10^{-14}\right) \approx 5.5 \times 10^{-14}\,\text{J}$

Question 10

The energy output of the Sun is due to the fusion reactions of protons (hydrogen ${}_{1}^{1}\mathrm{H}$) producing deuterium ${}_{1}^{2}\mathrm{H}$ and isotopes of helium ${}_{2}^{3}\mathrm{He}$, ${}_{2}^{4}\mathrm{He}$. There is a decrease in the total rest mass Δm_0 after each fusion reaction. The amount of energy released is given by $(\Delta m_0)c^2$.

Question 11

a. $f = \dfrac{c}{\lambda} = \dfrac{3.0\times10^{8}}{2.8\times10^{-2}} \approx 1.1\times10^{10}\,\text{Hz}$

b. Microwave $\lambda = 2.8\,\text{cm} >$ slit width $w = 1.5\,\text{cm}$.: diffraction of the microwave occurs at the two slits. The diffracted waves interfere to produce a pattern. At C and Q the path difference from the two slits is 0λ and 1λ respectively, resulting in constructive interference (strong microwave). At P and R the path difference from the two slits is $\frac{1}{2}\lambda$ and $\frac{3}{2}\lambda$ respectively, resulting in destructive interference (weak microwave).

c. Path difference $= \dfrac{3}{2}\lambda = \dfrac{3}{2}\times2.8\times10^{-2} = 4.2\times10^{-2}\,\text{m}$

d. $\Delta x = \dfrac{\lambda L}{d} = \dfrac{(2.8\times10^{-2})(1.5)}{15\times10^{-2}} = 0.28\,\text{m}$

e. The overall 'brightness' of the pattern decreases because there is less microwave passing through each slit. There is more diffraction at each slit and thus the pattern extends further at both ends but Δx remains the same.

Question 12

a. $a = g$ for weightless experience .: $\dfrac{v^2}{2.5} = 9.8$, $v \approx 4.95\,\text{ms}^{-1}$

b. $R + {}^{-}65\times9.8 = 65\times {}^{-}\left(\dfrac{1.50^2}{2.5}\right)$, $R \approx 580\,\text{N}$ upwards from the safety harness

Since $R \approx 580 < mg$.: the rider will feel lighter

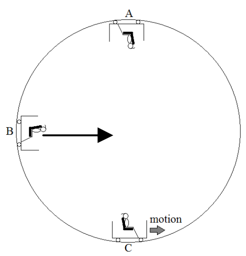
c. Total energy at A = total energy at C .: $65\times9.8\times5.0 + \frac{1}{2}\times65\times1.50^2 = 0 + \frac{1}{2}\times65\times v^2$, $v^2 = 100.25$

$R + {}^{-}65\times9.8 = 65\times {}^{+}\left(\dfrac{100.25}{2.5}\right)$, $R = 3243.5\,\text{N}$ upwards from the seat, $a = \dfrac{3243.5}{65} = 49.9 \approx 5.1g\ \text{ms}^{-2}$

$R = 3243.5 > mg$.: the rider will feel heavier.

d. At point C, $a > 5g$ and the passenger will pass out.

e.



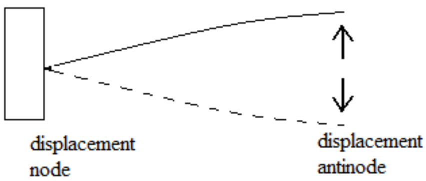
The reaction force is from the seat towards the centre of the circular path.

Question 13
The speed of sound (wave crests) does not change with the speed of the source.
When the fire-truck is moving, the siren emits sound at the same frequency. But the sound waves it emits forward to the stationary observer are closer together than normal (i.e. when it is at rest). This is because as the fire-truck moves, it is catching up with the previously emitted waves. Thus the stationary observer will detect more wave crests passing per second, i.e. the siren sound of the approaching fire-truck has a shorter wavelength and a higher frequency (pitch).
When the fire-truck passes the observer, the wave crests emitted behind the truck are farther apart than normal because the fire-truck is speeding away from them. Thus the stationary observer will detect less wave crests passing per second, i.e. the siren sound of the departing fire-truck has a longer wavelength and a lower frequency.

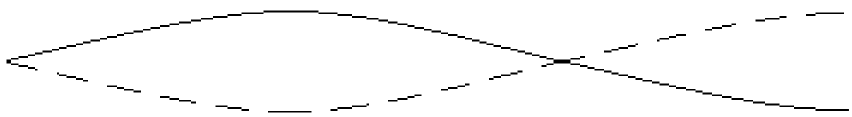
Question 14

a. $\frac{\lambda}{4} = 0.50$, $v = f\lambda = 4.0$ m s^{-1}

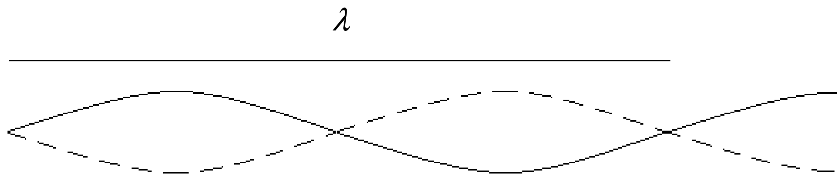
b.



c. Third harmonic



d.



$\lambda = \frac{4}{5} \times 1.5 = 1.2$ m

Question 15

a. $E = hf = (6.63\times10^{-34})(9.50\times10^{14}) \approx 6.30\times10^{-19}$ J

b. $f_0 = \frac{\phi}{h} = \frac{4.31\times10^{-19}}{6.63\times10^{-34}} \approx 6.50\times10^{14}$ Hz

c. $E_{k\,max} = hf - \phi \approx 6.30\times10^{-19} - 4.31\times10^{-19} = 1.99\times10^{-19}$ J

d. According to the photon model, the number of photons increases with the light intensity. Hence more photons are available for absorption and therefore more electrons will be emitted. Increasing the light intensity does not affect the photon energy and hence the maximum kinetic energy of the emitted electrons. The range of kinetic energy remains the same.

e. $(1.60\times10^{-19})V = 1.99\times10^{-19}$, collector potential $V \approx 1.24$ V

Question 16

a. Diffraction of electrons: In 1927 scientists scattered electrons from the surface of a metal crystal, observed that electrons came off in regular peaks. They interpreted the peaks as a diffraction pattern, the wavelength of the diffracted electron wave was found to be that predicted by de Broglie. Later experiments showed that protons, neutrons etc also have wave properties.

b. De Broglie's hypothesis that electrons have a wavelength $\lambda = \frac{h}{mv}$ gave an explanation for quantized states by bringing in the dual nature of matter. The quantised states correspond to circular waves in which the circumference of the electron orbit equals a whole number of wavelengths.

Question 17

Heisenberg's uncertainty principle says that position x and momentum p cannot be determined precisely, where p shows the direction θ of propagation of a particle. Both quantities contain uncertainties, Δx is the uncertainty in position and Δp is the uncertainty in momentum, and $\Delta x \Delta p \geq \frac{h}{2\pi}$.

A single slit diffraction of experiment (electron/photon) gives an excellent illustration of the principle. Consider the uncertainty in position Δx as the slit width when a particle passes through the slit. When the slit width decreases (smaller Δx, smaller uncertainty in position), the diffraction pattern becomes wider (larger Δp, greater uncertainty in momentum, i.e. larger range of θ and hence a wider central bright region).

Question 18

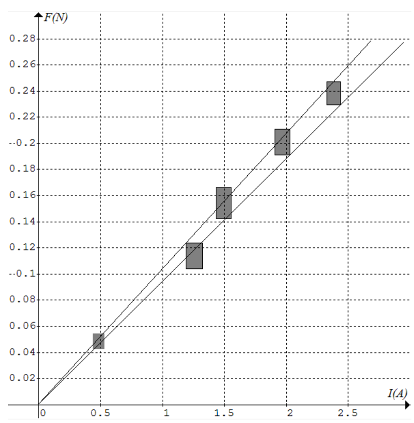
a. The magnets in the wooden box exert an upward force on the horizontal section of the U shape wire. According to Newton's third law, the horizontal section of the U shape wire exerts an equal but opposite force (i.e. downward force) on the magnets in the box sitting on the electronic balance.

b. The length of the horizontal section of the U shape wire; distance between the flat magnets on the walls of the wooden box.

c.

Resistance (Ω)	Multimeter readings (A)	I (A) with uncertainty	Balance readings (g)	F (N) with uncertainty
25	0.44, 0.47, 0.49, 0.52	0.48 ± 0.04	4.4, 4.8, 5.0, 5.4	0.048 ± 0.005

d.



e. Max gradient $\approx \frac{0.26}{2.5} \approx 0.104\,\text{NA}^{-1}$, min gradient $\approx \frac{0.26}{2.75} \approx 0.095\,\text{NA}^{-1}$

Average gradient $\approx \frac{0.104 + 0.095}{2} \approx 0.099\ \text{NA}^{-1}\ \pm 0.005$

f. $F = kI$ where F is in N, I in A, and $k = 0.099 \pm 0.005\,\text{NA}^{-1}$