PHYS1902 Advanced Exam Solutions
Semester 2, 2005

Question 1

(a) By the equation of continuity,

$$A_A v_A = A_B v_B = A_C v_C$$

so since $A_B < A_A < A_C$, then

$$v_B > v_A > v_C$$

Since it is an ideal fluid, we can use Bernoulli's equation: ρ + 1/2 ρv^2 = constant, so

$$P_C > P_A > P_B$$

and the pressure at the exit is equal to atmospheric pressure, so $P_A = P_{exit} = P_{atm}$

(1 mark)

Fluid will leak out only if the pressure inside the pipe at the position of the hole is greater than atmospheric pressure

(1 mark)

Hence the fluid will leak from a hole drilled at point C, but not holes at points A or B.

(1 mark)

(b) Using the Reynolds Number:

$$\frac{\rho v L}{\eta} = \frac{(800)\times 0.1\times 0.1}{2\times 10^{-3}} \approx 4000 \text{ on the boundary of turbulence}$$

(2 marks for sensible attempt)

(Total 5 marks)

Question 2

(a) Insufficient information.

A positive charge feels an electric force downwards, and an equal magnetic force upwards. A negative charge feels the electric force upwards and the magnetic force downwards. (Also acceptable: In both cases, the charge "cancels out" of the equation.)

(2 marks)

(b) The electric force has magnitude $F = qE$, and the magnetic force has magnitude $F = qvB$ in the opposite direction.

The forces must balance.

The expression is $v = E/B$.

(3 mark)

(Total 5 marks)

Question 3

(a) Capacitor discharges through the inductor, because there is a complete circuit when the switch is closed.

(1 mark)

(b) As the capacitor discharges, a back emf develops in the inductor resulting in the capacitor being charged in the opposite sense; then the capacitor discharges again. The cycle repeats itself continuously. (LC resonance circuit).

(1 mark)

(c) Sinusoidal graph. (Also accept a decaying sine curve, because the coil may have some resistance.) Because we haven't asked for a "graph", axes labels etc are not required.

(1 mark)

(d) The energy oscillates (resonance circuit)

(1 mark for identifying oscillation)

between 1) being stored in the electric field of the capacitor, and 2) being stored in the magnetic field surrounding the inductor.

(1 mark for identifying where the energy is stored)

(Total 5 marks)

Question 4

The origin of St Elmo's fire is closely related to the physics behind lightning rods. During a thunderstorm, the electric field in the atmosphere is ~10^6 V.m^{-1} – well above the clear weather value of ~100 V.m^{-1}. This field attracts charge to high places – closer to the opposite charges in the clouds. In particular charge accumulates in pointy conductive objects – trees, church steeples, lightning rods – or masts of ships. Since the charge density is highest at these places, the electric field is also high there (since $E \sim \sigma/\varepsilon_o$, where σ is the charge density).

(Charge accumulation at points - 1 mark)
(Field highest at points - 1 mark)

Where the field exceeds ~3 x 10^6 V.m^{-1}, the air can spontaneously break down as electrons are ejected from their atoms, in turn ejecting further electrons. These electrons later re-combine with their atoms which emit light at characteristic wavelengths. In the nitrogen/oxygen mixture of air this colour is characteristically blue/violet – as observed in St Elmo's fire. This is an example of a "glow discharge" or "coronal discharge".

(Explain breakdown in air - 1 mark)
(Explain why light is emitted - 1 mark)

The effect will concentrate around the pointy ends of masts (or yards) on sailing ships, especially when they are wet, thus maximizing their conductivity.

(Why wet masts or other sensible details - 1 mark)

(Total of 5 marks)

Question 5

(a) De Broglie's hypothesis has $p = \dfrac{h}{\gamma}$

But $KE = \dfrac{p^2}{2m} = \dfrac{h^2}{2m\lambda^2}$

Then if energies are the same

$M_e < M_n < M_\alpha \Rightarrow \lambda_e > \lambda_n > \lambda_\alpha$

(2 marks)

(b) $v = \dfrac{h}{m\lambda} = \dfrac{6.6 \times 10^{-34}}{4 \times 1.7 \times 10^{-27} \times 0.01}$

$= 1 \times 10^{-5}\, m.s^{-1}$

(2 marks)

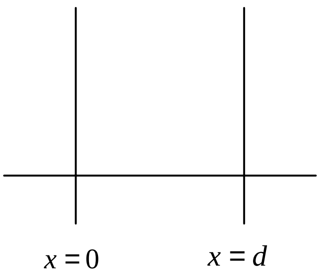
(c) Exclusion principle allows only two electrons to enter the 1s state since there are only two available distinct states (spin up electron and one spin down). The next lowest available state is 2s for the extra electron.

(1 mark)

(Total 5 marks)

Question 6

(a)



1-D motion

$\Delta x\, \Delta P_x \geq h$ is the Heisenberg principle. The better we know the position, the less well we know momentum.

(2 marks)

(b) $\Delta x \sim \dfrac{d}{2}$

(1 mark)

$\Delta P_x \sim \dfrac{2D}{d}$

(c) $P_x \geq \frac{2D}{d} \Rightarrow KE \geq \frac{2h^2}{md^2}$

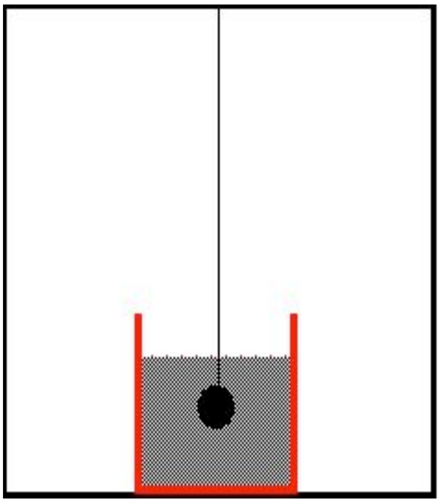
(2 marks)

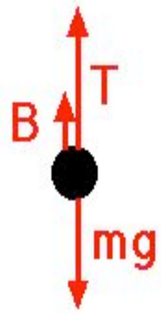
$$\Rightarrow KE \geq \frac{h^2}{2\pi^2 md^2} = \frac{(6.6\times10^{-34})^2}{2\times9.87\times9.1\times10^{-31}\times10^{-20}}$$

$$= 2.4\times10^{-18}\ \text{J}$$

15 eV

Question 7





(2 marks for diagram)

Mass of stone m = 3 kg.

(a) At rest, T = 21 N. From the force diagram,

$$T + B = mg$$ **(1 mark)**

Hence bouyancy force $\text{B} = \text{mg} - \text{T} = 3\times 9.8\text{N} - 21.0\text{N} = 8.4N = mwg$ **(1 mark)**

(b) (i) When the lift is accelerating upward with acceleration a, the sum of the applied forces on the stone must equal the mass times the acceleration:

$$T + B - mg = ma$$

The weight of water displaced is $m_w(g+a)$, since the water is accelerating upwards. Hence

$$T = mg + ma - m_w(g+a)$$
$$= (m - m_w)(g+a)$$

(3 marks)

(ii) When a = 2.5 ms^{-1} upwards, $mw = 8.4/9.8\,kg$,

$$T = (3.0 - 8.57\text{x}10^{-4}\text{x}1000)(9.8+2.5)$$
$$= 26.4\ \text{N}$$

(1 mark)

Question 7 ….. continued

(c) When the lift is in free fall, the downward acceleration is *g*, so the weight of the water is $m_w (g - g) = 0$ N, i.e. the water provides no buoyancy. The tension in the cord is

$$T = (3.0 - 8.57\text{x}10^{-4}\text{x}1000)(9.8\text{–}9.8) = 0 \text{ N}$$

In free-fall, there is no tension in the cord, which is what we would expect.

(2 marks)

(Total 10 marks)

(NOTE: 1 mark for correct answer. 1 mark for correct reasoning. No mark given if rock is stated to float to surface. ie. buoyancy pushes it upwards)

Question 8

(a) Sketch of field: – zero inside inner cylinder and outside outer cylinder
– radially outwards between the cylinders **(1 mark)**

Use symmetry and Gauss' Law. Use Cylindrical Gaussian surface
$\Phi = 2\pi r L E(r)$ **(method – 1 mark)**

Inside, $E = 0$ since $q_{enc} = 0$. Same for outside.

Between, $q_{enc} = L\lambda \quad \Rightarrow E = \frac{1}{2\pi\varepsilon_0} \lambda/r \quad a < r < b$ **(1 mark)**

$$\left.\begin{matrix} 0 & r < a \\ 0 & r > b \end{matrix}\right\}$$ **(1 mark)**

(b) $V = \int_a^b E dr \quad \text{since } E \parallel dl$

(1 mark)

$$= \frac{\lambda}{2\pi\varepsilon_0} \int_a^b \frac{dr}{r}$$

$$= \frac{\lambda}{2\pi\varepsilon_0} \ln\left(b/a\right)$$ **(1 mark)**

(c) $C = q/V = \frac{\lambda L}{V}$ **(1 mark)**

$$\Rightarrow \quad \frac{C}{L} = \frac{2\pi\varepsilon_0}{\ln\left(b/a\right)}$$ **(1 mark)**

(d) $U = \frac{q^2}{2C}$ **(1 mark)**

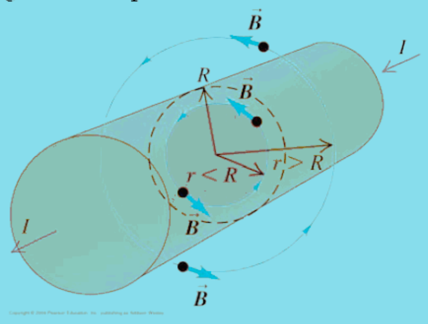
$$U = \frac{1}{2} \frac{\ln\left(b/a\right)}{2\pi\varepsilon_0 L} \lambda^2 L^2 = \frac{\ln\left(b/a\right)}{4\pi\varepsilon_0} \lambda^2 L$$ **(1 mark)**

(Total of 10 marks)

Question 9

(a) From symmetry arguments, the magnetic field is in circles. **(1 mark)**

Apply Ampere's Law using a circular path of radius r (as illustrated) **(1 mark)**



We use the fact the B has constant magnitude along the path and is parallel to the path. **(1 mark)**

Thus Amperes law gives $B(2\pi r) = u_0 i$

And thus $B(r > R) = \dfrac{u_0 i}{2\pi r}$ **(1 mark)**

(b) Similar argument but with $i(r) = \dfrac{r^2}{R^2} i$ inside the cylinder **(1 mark)**

yields $B(r < R) = \dfrac{u_0 i r}{2\pi R^2}$ **(1 mark)**

(c) Again, Ampere's law is applied. For circular paths of radius $r>2R$, the two opposing currents cancel, given a net current of zero. The magnetic field in the region $r>2R$ is zero.

(1 mark)

(d) The magnetic field in the region $R < r < 2R$ is the same as given in part (a). The answer has not changed because the current in the outer shell does not contribute for circular paths of radius $r < 2R$, because it flows outside of the paths.

(1 mark)

(e) Inside outer shell: B circular – anticlockwise sense

(1 mark)

Outside shell: B zero (no lines)

(1 mark)

(Total 10 marks)

Question 10

(a) We choose a circular path of radius r. The magnetic field is constant on this path, and is directed tangentially. Ampere's Law gives:

$B \cdot 2\pi r = \mu_0 i$ which is rearranged to give $B = \dfrac{\mu_0 i}{2\pi r}$

(1 mark for magnitude)

The direction is into the page. **(1 mark for direction)**

(b) The magnetic field is constant over the infinitesimal strip, and is directed perpendicular to the plane defined by the strip.

(1 mark for argument)

$$d\Phi_B = B \cdot dA = \frac{\mu_0 i}{2\pi r} L \cdot dr$$

(1 mark for result)
(full marks for only the result)

(c) The total magnetic flux is found by integrating $d\Phi_B$ from $r=a$ to $r=b$. **(1 mark)**

$$\Phi_B = \int_a^b d\Phi_B = \int_a^b \frac{\mu_0 iL}{2\pi} \frac{dr}{r} = \frac{\mu_0 iL}{2\pi} \ln\left(\frac{b}{a}\right)$$ **(1 mark for correct integration)**

(d) The induced emf is determined by Faraday's Law.

$$-\frac{d\Phi_B}{dt} = -\frac{\mu_0 L}{2\pi} \ln\left(\frac{b}{a}\right)(di/dt)$$ **(1 mark for use of Faraday's Law)**

(1 mark for formula)

Only *i* is dependent on time, and so there is only one term in the derivative.

(e) The induced emf is counterclockwise.

(1 mark)

The magnetic flux through the loop is directed into the page and is increasing, because the current is increasing ($di/dt > 0$). The induced emf will serve to create an induced field to counter this increase, i.e., out of the page.

(1 mark)

(Total 10 marks)

Question 11

(a) λ_m = peak wavelength T = temperature in Kelvin

(1 mark)

λ_m is inversely proportional to T, so their product is a constant.
i.e. a body that has shorter peak wavelength is hotter than that with longer wavelengths peak.

(1 mark)

So, we can measure the temperature of a hot object from its radiated spectrum *or* predict its radiated spectrum from its temperature.

(1 mark)

(b) Classical physics predicts that the emittance $I(\lambda)$ increases monotonically with frequency (decreases with wavelength) and that the total radiated power goes towards infinity at high frequencies (short wavelengths), both of which are experimentally incorrect. Quantum physics resolves this by quantising the photons.

(2 marks)

(c) Photon Energy $E = hf = \dfrac{hc}{\lambda}$

(1 mark)

Equating this with translational energy $\dfrac{hc}{\lambda} = \dfrac{3}{2}kT \quad \Rightarrow \quad \lambda T = \dfrac{2hc}{3k}$

(1 mark)

Inserting values $\lambda T = \dfrac{2hc}{3k} = \dfrac{2\left(6.62607 \times 10^{-34}\right)\left(3.00 \times 10^{8}\right)}{\left(1.38 \times 10^{-23}\right)} = 9.6 \times 10^{-3}$

i.e $\lambda T = 0.01$ m·K.

(1 mark)

The equations have the same general form; for wavelengths shorter than λ_{m} the photon energy is much larger than might be expected from thermodynamic arguments and hence those photon are rare, consistent with Wien's displacement law.

(2 marks)

(Total 10 marks)

Question 12

(a) The momentum of a photon is given by $E = \hbar k = \frac{h}{\lambda}$

(1 mark)

(b) The Balmer series is the one for electron transitions to the level with principal quantum number n = 2 from an excited state with n > 2.The longest wavelength corresponds to the transition n = 3 to n = 2. The wavelength is$1/\lambda = R_H(1/4 - 1/9)$

(3 marks)

(c) The change in momentum is $hk = \Delta p = \hbar k = h/\lambda = 6.63x10^{-34} R_H(1/4 - 1/9)$
with $R_H = 1.0968 \times 10^7 \mathbf{m^{-1}}$
This reduces the velocity of the hydrogen atom by$\Delta v = \frac{\Delta p}{m} = 1110 m/s$

(4 marks)

(d) The atom is moving relative to the lab frame of reference and so there is a Doppler blue shift that needs to be allowed for if the absorbing atom is to resonantly absorb the photon.

(2 marks)

(Total 10 marks)