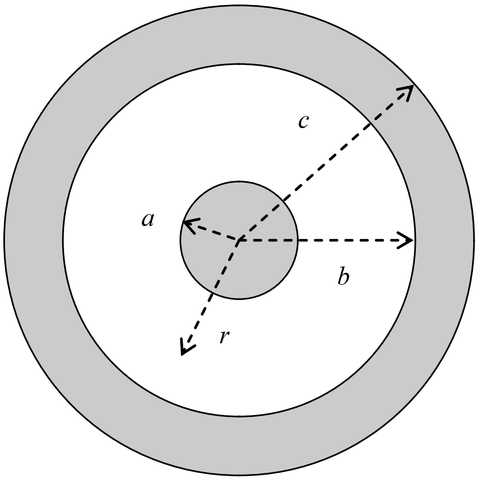
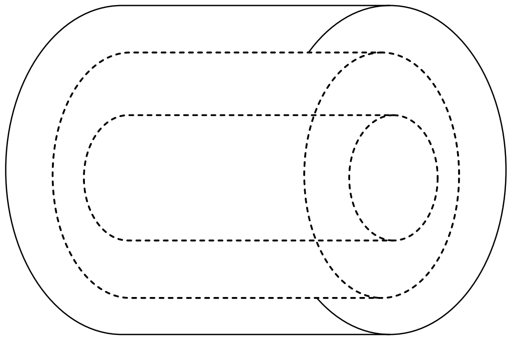
Question 1 [25 marks]

The figure below shows the cross-section of a coaxial cable, a long-cylindrical shaped cable that is used to carry electrical signals. The inner conductor has a radius *a*, while the outer conducting hollow cylinder has inner radius *b* and outer radius *c*. Equal but oppositely directed uniform distributed currents *I* exist in the two conductors. That is, the current flows one way in the inner conductor, the opposite way down the outer conductor.



Cross section



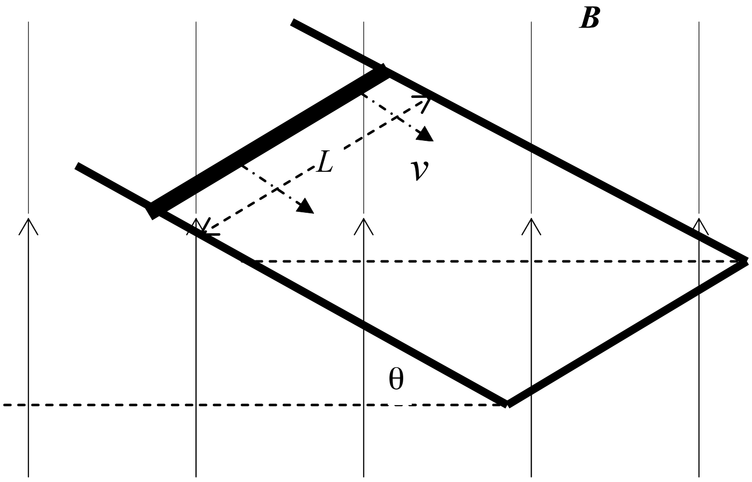
Side view

a) State Ampere's Law, explaining the meaning of all symbols used.
b) Explain the importance of choosing an appropriate Amperian loop in applying Ampere's law to determine magnetic fields. Sketch a suitable Amperian loop(s) for use in determining the magnetic field produced by the coaxial cable, as sketched above.
c) Derive expressions for the magnetic field *B(r)* produced by the cable in each of the following regions:
   (i) $r < a$
   (ii) $a < r < b$
   (iii) $b < r < c$
   (iv) $r > c$
   where *r* is the distance measured from the centre of the cable.
d) If $a = 0.040$ cm, $b = 1.80$ cm, $c = 2.00$ cm, and $I = 120$ mA, sketch the magnetic field produced by the cable, *B(r)*, as function of *r*, for all regions considered in part c).
e) Hence, or otherwise, calculate the inductance per metre of the coaxial cable. [Hint: Calculate the flux through a rectangular surface of length *l*, perpendicular to the magnetic field, for $a < r < b$. Ignore the contribution of flux inside the conductors. Recall also that inductance can be defined as

$$L = \frac{N\Phi_B}{I}$$]

Question 2 [15 marks]

A metal rod with length L, mass m, and resistance R slides without friction down parallel conducting rails of negligible resistance, as shown in the diagram below. The rails are connected together at the bottom as shown, forming a conducting loop with the rod as the top member. The plane of the rails makes an angle θ with the horizontal and a uniform vertical magnetic field $\boldsymbol{B}$ exists throughout the region.

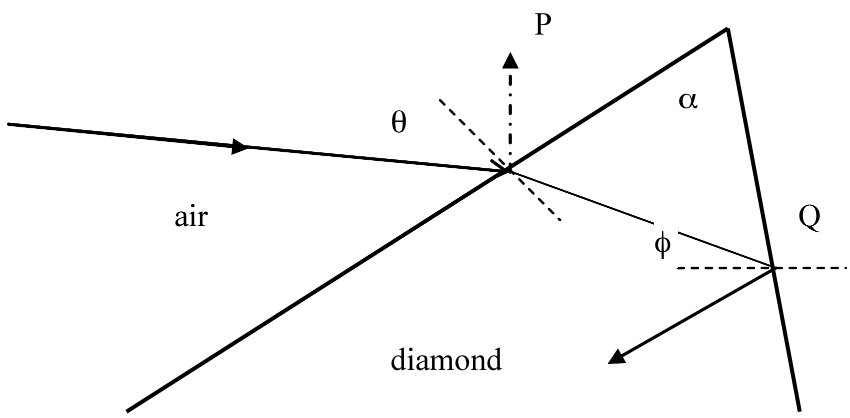


a) Consider at some moment that the rod is currently sliding at a velocity v and a current I flows through it. Draw a free body diagram, illustrating all the forces that are acting on the rod.
b) Indicate the direction at which the induced current will flow down the rod.
c) Explain why the rod will eventually reach a constant velocity of descent (terminal velocity).
d) Show that the magnitude of this terminal velocity is

$$v = \frac{mgR}{B^2L^2}\frac{\sin\theta}{\cos^2\theta}$$

Question 3 [25 marks]

Unpolarised white light is incident on a Diamond crystal as shown in the diagram below. Take the refractive index of Diamond as n = 2.42, and the crystal sits in air.



The diamond crystal has been cut such that the back surface of the crystal makes an angle α = 42.3° to the incident crystal surface.

a) Derive the condition for the total internal reflection at Q,

$$\sin\phi = 1/n$$

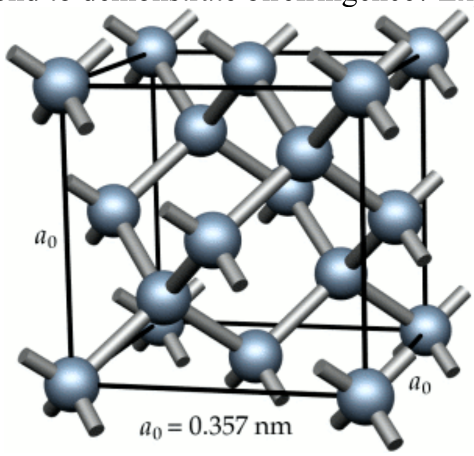
b) Find the range of incident angles, θ, for total internal reflection to occur at Q.

c) In two or three clear sentences, explain the concept of 'dispersion', and its importance in jewelry, such as the diamond crystal considered in this question.

d) Now, find the incident angle θ for the light reflected at P (the first air-diamond surface) to be completely plane polarised.

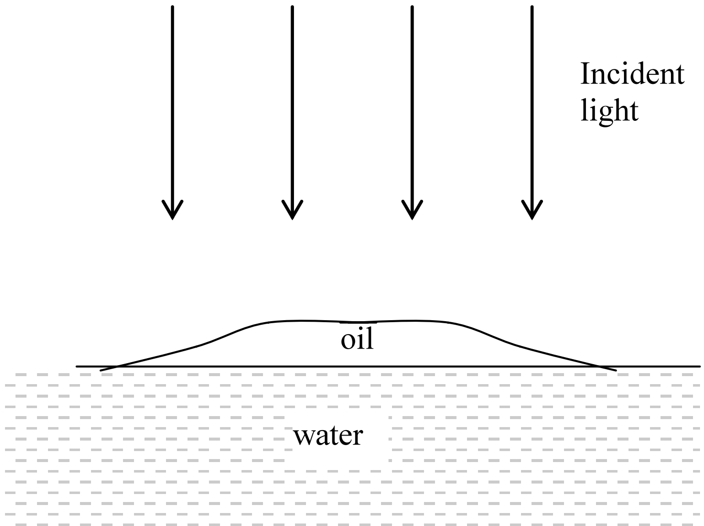
e) With a clear diagram, show the direction of polarisation the light reflected at P.

f) The crystal structure of diamond is shown in the diagram below. Given this structure, would you expect diamond to demonstrate birefringence? Explain your answer.



Question 4 [15 marks]

An oil drop (n = 1.20) floats on a water (n = 1.33) surface, and the reflected light is observed from above.



a) Will the outer (thinnest) regions of the drop correspond to bright or dark regions? Carefully explain your answer.
b) How thick is the drop when one observes the third blue fringe, taken from the outer edge of the drop? (Take the wavelength of blue light as 350 nm)
c) Why do the colours gradually disappear as the oil thickness becomes larger?

Question 5 [20 marks]

Laser light of wavelength λ = 620 nm is shone at a pair of narrow slits, separated by 0.040 mm. The intensity of the laser light at the slits is $1.0\,\mathrm{mWm^{-2}}$. The pattern is observed on a screen a distance of 2.50 m behind the slits.

a) Sketch the pattern observed on the screen, giving numerical values for the spacing between any fringes in the pattern.
b) In no more than two clear sentences, explain how the pattern you sketched in a) is compelling evidence for the wave nature of light.
c) With no more than a few sentences for each, describe TWO phenomena that cannot be explained by the wave model of light.
d) Imagine that we had a photon detector at each of the slits, which could detect whether the photon of light went through the left slit or the right slit. Sketch the pattern that we would observe on the screen now.
e) How does Quantum Mechanics explain the difference between the patterns as your answers to part a) and d)?
f) Determine the number of photons per m^2 per second striking the slits.

Question 6 [20 marks]

Bohr proposed a model of the atom featuring electron orbitals and corresponding energy levels that were quantised, but was otherwise based on classical physics principles.

a) Briefly describe Bohr's model, making sure to state his three postulates and his quantization condition.
b) Show that the electron energies in Bohr's model are

$$E_n = -\frac{m_e e^4}{8\varepsilon_0^2 h^2}\frac{1}{n^2}, \quad n = 1,2,3\ldots$$

c) How was de Broglie able to explain Bohr's quantization condition?
d) Calculate the wavelength of radiation emitted when a Hydrogen atom relaxes from the n = 5 orbital to the ground state (n = 1).
e) Explain briefly TWO features of Schrödinger's solution of the Hydrogen atom that could not be explained by Bohr's model and Classical physics in general.