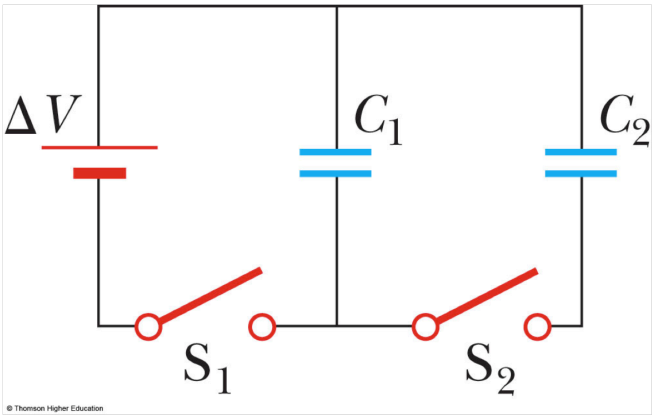
Question 1. (Marks 16)

Consider the circuit shown in the figure, where $C_1 = 6.00\mu F$, $C_2 = 3.00\mu F$, and $\Delta V = 20.0V$. Capacitor C_1 is first charged by closing switch S_1. Switch S_1 is then opened, and the charged capacitor is connected to the uncharged capacitor by closing S_2.



(a) Calculate the initial charge acquired by C_1, after S_1 is closed.

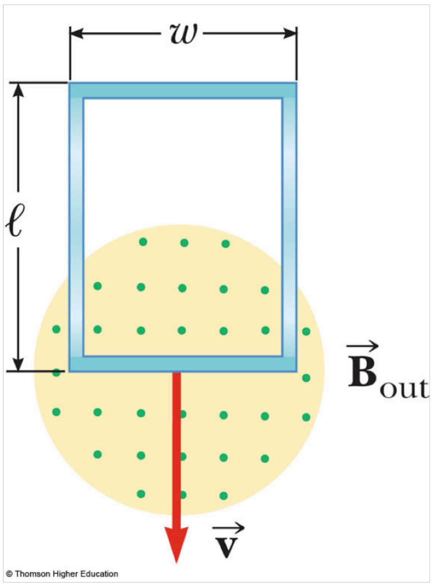
(b) Calculate the final charge on each capacitor.

(c) Calculate the final voltage on each capacitor.

(d) Suppose you have a voltage source and two capacitors with different capacitances. The capacitors are initially in an unknown state of charge. You also have some lengths of copper wire that can be used to connect the components together, and/or to discharge the capacitors. What procedure could you follow to place the same, non-zero, charge on each capacitor? Illustrate your answer with diagrams to show the connections between the components.

Question 2. [Marks 24]

The figure shows a rectangular loop of width w, length l, mass M and resistance R falling through a region of uniform magnetic field strength B, directed out of the page. The magnitude of the velocity of the loop at any instant is v. The loop is made from conducting wire.



During the time interval before the top edge of the loop reaches the field, and before any part of the bottom edge of the loop leaves the field,

(a) State, with reasoning, whether the direction of the induced current I in the loop is clockwise or counterclockwise.

(b) Derive an expression for the rate of change of magnetic flux through the loop.

(c) Derive an expression for the power dissipated in the loop.

(d) The loop will approach a terminal speed v_T . Derive an expression for this speed in terms of the properties of the loop, the magnetic field strength B, and the acceleration due to gravity g.

(e) How would the numerical value of v_T change if the rectangular loop was replaced by a coil of N rectangular loops of the same dimensions as the original loop, made from the same resistivity wire as used for the original loop, and with the ends of the coil connected together so as to produce a continuous circuit?

Question 3. (Marks 22)

(a) An electromagnetic (EM) sinusoidal plane wave with frequency $f = 90.0$ MHz propagates in the $+x$ direction. The electric field of the EM wave has a peak value $E = 2.00$ mV/m directed along the $\pm y$ direction.

(i) Find the wavelength, period and the maximum value of the magnetic field for this EM wave.

(ii) Write down expressions for the space and time variations of the electric and magnetic fields; give the expressions in SI units. Include in your expressions the appropriate unit vectors $\hat{\mathbf{i}}, \hat{\mathbf{j}}, \hat{\mathbf{k}}$.

(iii) Find the average power per unit area carried by this wave.

(iv) Find the average energy density in the radiation.

(b) Light with free space wavelength $\lambda = 780$ nm travels a distance $2\text{x}10^{-6}$ m in a transparent medium of refractive index 1.6. Calculate,

(i) the optical path length,

(ii) the wavelength of the light in the transparent medium,

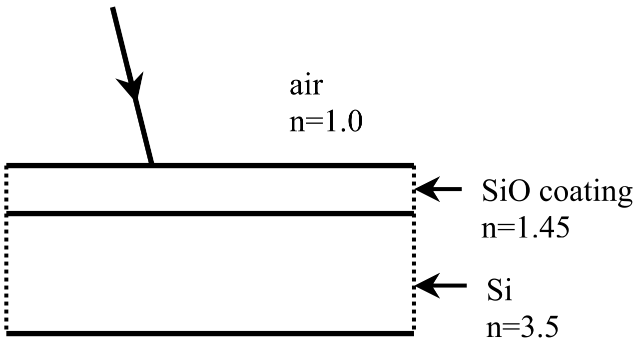
(iii) the phase difference after travelling a distance $2\text{x}10^{-6}$ m with respect to light travelling the same distance in free space.

Question 4. (Marks 15)

(a) Consider a Young's double slit apparatus in which the centre-to-centre slit spacing is 0.3mm and the slits-to-screen distance is 0.8m. Two wavelengths of light λ_1, λ_2, illuminate the slits simultaneously, where $\lambda_1 = 500$ nm and $\lambda_2 = 600$ nm, producing two interference patterns on the screen. Find the separation (distance) on the screen between the two third-order interference patterns produced by λ_1, λ_2.

(b) To maximize collection efficiency by minimizing reflective losses, the surface of silicon (Si) solar cells can be coated with a thin film of silicon monoxide (SiO).

(i) On the diagram below, representing a SiO coated Si solar cell, sketch in transmitted and reflected rays, indicating on the sketch all phase changes, for both the transmitted and reflected rays, occurring at the air-SiO and SiO-Si interfaces.



(ii) For the SiO coated Si solar cell, calculate the minimum film thickness required to minimize reflection losses of solar radiation of wavelength $\lambda = 550$ nm. (Refractive indices: Silicon cell: $n_{Si} = 3.5$; Coating, $n_{SiO} = 1.45$)

Question 5 (Marks 10)

A student attends a physics lecture with a camera to record the notes the lecturer has projected on to the theatre's screen. The camera has a lens diameter of 2mm. The lecturer has written the notes in blue ink (λ_{blue} = 450 nm) and each character (letter or symbol) can be considered to be a 3mm diameter circle on the screen.

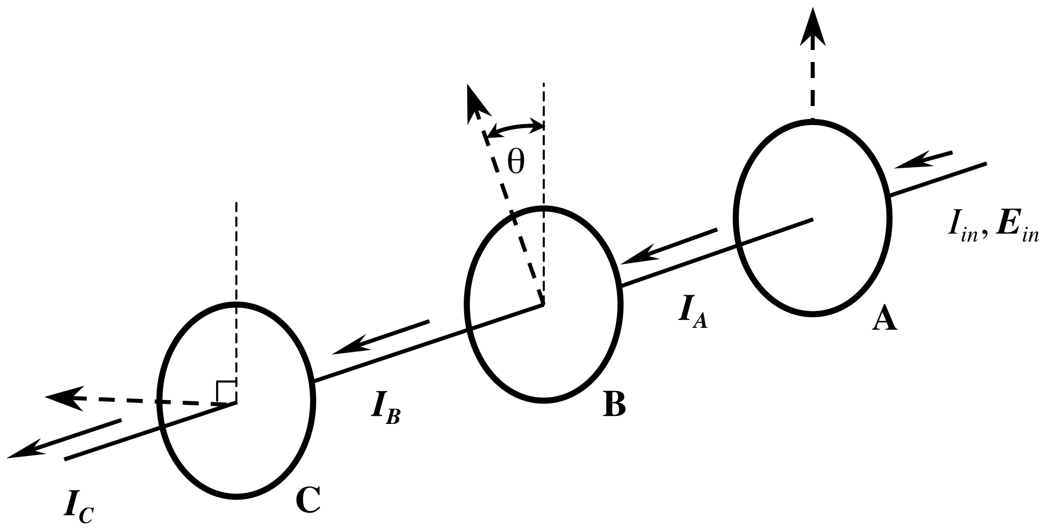
(i) Will the camera resolve individual characters on the screen if the student sits at the back of the theatre, at a distance of 25 m from the screen? If not,

(ii) what is the minimum distance the camera must be from the screen such that individual characters are just resolvable?

Note: a plain yes/no answer will obtain no marks; the principle and argument used to show resolvability must be given, with a simple sketch if appropriate, along with all working in your calculation.

Question 6 (Marks 11)

Three ideal polarizing sheets are arranged as shown below. Unpolarized light of intensity I_{in} is incident upon polarizing sheet A. The polarization axes of the sheets are indicated by the broken arrows. Sheets A and C are arranged as shown with their axes of polarization at 90º (A at 0º and C at 90º), sheet C is rotated such that its polarization axis is at angle θ to the vertical (and therefore also at θº to the polarization axis of sheet A).



(i) What is the intensity of light transmitted by sheet A?

(ii) If $\theta = 45°$, find the intensity of light transmitted by each of the three sheets and therefore that transmitted by the system of sheets A, B and C (i.e. A, B and C together).

(iii) If $\theta = 30°$, find the intensity of light transmitted by the system.

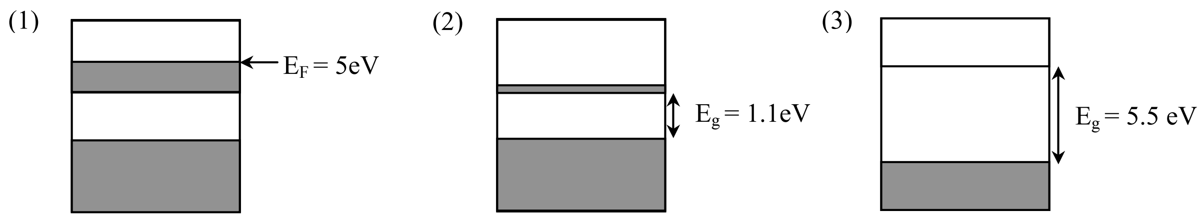
Question 7 (Marks 22)

(a) Calculate the de Broglie wavelength of a 25kV electron. State whether relativistic corrections are significant? (Support your statement with a numerical estimate.)

(b) The lifetime of the unstable hydrogen $n = 2$ state is approximately 10 ns. Using Heisenberg's Uncertainty Principle determine the number of significant figures that may be used to express its energy.

(c) Provide a simple *labelled* sketch showing the fundamental difference between a direct and an indirect gap semiconductor. Name one semiconductor material of each type.

(d) Three materials have the energy band structures shown schematically in the diagram below representing, (1) a metal, (2) an n-type doped semiconductor and (3) an insulator. The shaded areas indicate energy ranges occupied by electrons.



(i) For the metal shown in (1), find the Fermi velocity and the thermal velocity of the electrons at 300K.

(ii) Find the wavelength of EM radiation that will cause a sharp increase in the electrical conductivity of material (2).

(iii) By considering the energy gap values for materials (2) and (3) state, with your reasoning, whether the materials are expected to be transparent or opaque to visible light at room temperature. (The visible region of the EM spectrum spans the wavelength range λ=400nm to λ=700nm approx.)