Question 1: [12 marks]

A highly advanced alien race decides they want to play pool with planets. In the vast void between galaxies, they take two Earth-mass planets (coated with a perfectly conducting metal), and place them so that their centres are 200,000 km apart. In order to balance the gravitational attraction between the planets, the aliens add equal numbers of electrons to each planet so that the electric force between the planets precisely balances the attraction between them due to gravity.

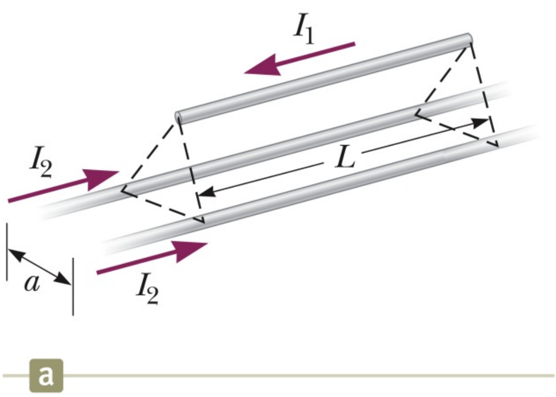
a) Draw a figure showing the forces acting on each of the planets [3 marks]

b) How many electrons do the aliens have to add to each planet such that the electric force exactly balances the gravitational force between the planets? [6 marks]

c) What mass of electrons does this correspond to? [1 mark]

d) Assuming the planets are perfectly spherical, how are the electrons distributed once added? [2 mark]

Question 2: [10 marks]



Two infinitely long, parallel wires are lying on the ground a distance a = 12.5 cm apart. A third wire, of length L = 100.0 m, and mass 35.0 kg, carries a current of I_1 = 1000 A, and is levitated above the first two wires at a horizontal position midway between them, as can be seen in the figure. The two parallel wires carry equal currents (I_2) in the opposite direction to that flowing through the levitated wire.

a) Draw a figure showing the situation as viewed end on. Show the various forces acting on the levitated wire, and the currents flowing through the wires. [4 marks]

b) What current must the infinitely long wires carry so that the three wires form an equilateral triangle? [6 marks]

Question 3: [12 marks]

You have two identical capacitors, each of which has a capacitance of 10,000 F, and a 120 V battery.

a) Calculate the total energy stored in both capacitors if they are connected *in series* across the battery. Draw a circuit diagram showing how the capacitors are connected to the battery in this case. [4 marks]

b) Calculate the total energy stored in both capacitors if they are connected in *parallel* across the battery. Again, draw a circuit diagram showing how the capacitors are connected to the battery. [3 marks]

A thunderstorm is essentially a giant parallel-plate capacitor. Imagine a giant thunderstorm over Sydney. For simplicity, assume that the base of the thundercloud is circular, with a radius of 15.0 km, and that the cloud base is 1 km above the ground.

c) Calculate the capacitance of the thunderstorm. [3 marks]

A lightning strike causes the thunderstorm to completely discharge, transferring 2.53 C of charge and 1.94×10^6 J of energy to the Earth.

d) Calculate the potential difference that existed between the cloud and the ground just prior to the lightning flash. [2 marks]

Question 4: [18 marks]

a) Explain, in words, Gauss' law for electric flux. [1 mark]

b) Give the mathematical form for Gauss' law for electric flux [1 mark]

An insulating solid sphere of radius, *a*, has a uniform volume charge density, and carries a total positive charge of magnitude, *Q*.

c) Calculate the magnitude of the electric field at a point outside the sphere [3 marks]

d) Calculate the magnitude of the electric field at a point inside the sphere [3 marks]

e) Draw a graph showing the variation of the electric field as a function of distance, *r*, from the centre of the sphere. [1 mark]

f) Give the mathematical form for Ampère's law, and define the terms used [2 marks]

A long, straight wire of radius R carries a steady current I that is uniformly distributed through the cross section of the wire.

g) Calculate the magnetic field a distance r from the centre of the wire in the region $r \geq R$ [3 marks]

h) Calculate the magnetic field in the region $r < R$. [3 marks]

i) Draw a graph showing the variation of the magnetic field as a function of the distance r from the centre of the wire [1 mark]

Question 5: [12 marks]

Hydrogen-alpha (Hα) radiation is emitted when the electron in an excited hydrogen atom falls from the third to the second lowest energy level. When passing through a vacuum, Hα light has a wavelength of 656 nm, putting it in the red part of the visible electromagnetic spectrum.

a) What is the frequency of Hα radiation? [1 mark]

An astronomer takes a photograph of the Orion nebula, a bright source of Hα light, using a lens made from fused quartz, which has a refractive index of 1.46 for red light.

b) What is the wavelength of the Hα radiation when it is passing through the lens? [2 marks]

c) The aperture of the astronomer's lens is 3.00 cm. What is the limiting angle of its resolution for Hα light? [2 marks]

Hα is one of a series of spectral lines emitted by electrons falling to the second energy level in hydrogen. A second line, known as Hydrogen-beta (Hβ), falls at a wavelength of 486 nm, and is the result of electrons falling from the fourth to the second energy level.

Our astronomer wants to study the spectrum of the Orion nebula, and so uses a telescope to direct its light, at normal incidence, onto a diffraction grating with 600 lines/mm.

d) What is the angular separation between the first-order maxima for Hα and Hβ? [5 marks]

e) The spectrum projected from the diffraction grating illuminates a photographic plate which can be moved towards and away from the grating. If the astronomer wants the two lines to be separated by 10 cm on the photographic plate, how far from the grating must the plate be placed? [2 marks]

Question 6: [12 marks]

A student wants to experiment with the laws of reflection and refraction, and takes a cube of flint glass (with refractive index 1.66, and sides of length 10 cm) and an equal sized cube of pure ice (refractive index 1.31), and two plane mirrors, which are 20 cm long.

The student places the first mirror flat, face up, on the table, and places the two cubes on top of it, touching one another, and then places the second mirror, face down, on top of them.

The student then shines a ray of light at the sandwiched mirrors and cubes such that it hits the ice block halfway between the mirrors, incident at an angle of 75 degrees to the normal.

a) Draw a figure that shows the path of the light from the air, through the ice, then through the glass, and finally exiting from the glass. [4 marks]

b) How far from its entry point to the ice does the ray of light first hit a mirror, measured horizontally? [4 marks]

c) At what angle to the normal does the ray emerge from the ice into the flint glass? [2 marks]

d) At what angle to the normal does the ray emerge from the flint glass? [2 marks]

Question 7: [13 marks]

The peak intensity of the Solar spectrum falls in the yellow part of the spectrum, where the eye is most sensitive.

a) If that maximum intensity falls at a wavelength of 502 nm, calculate the temperature of the Sun's surface. State any assumptions you make. [3 marks]

b) A leaf, which we can model as a rectangle with sides 5.0 cm and 2.0 cm long, is illuminated in full sunlight, and receives a flux of 1.0 W. Using the average distance from the Earth to the Sun, calculate the radius of the Sun. State your assumptions. [8 marks]

c) Is the radius you just calculated likely to be an overestimate, or an underestimate? State your reasoning. [2 marks]

Question 8: [11 marks]

a) State the time-independent Schrödinger equation, defining each term that you use. [2 marks]

b) Sketch the wave functions, Ψ, and probability densities $|\Psi^2|$ for a particle in a potential well with finite height, for n = 1, 2 and 3 [6 marks]

c) Explain in words, and give the mathematical form of the Heisenberg uncertainty principle. [3 marks]