1) According to Descartes, a rainbow is formed as a result of the passage of sun's light through drops of water. Rays undergoing a single internal reflection inside the drops yield the so-called primary bow, whilst the secondary bow is formed by rays that undergo double reflection. Assuming the drop of water to be spherical, calculate the angle of deviation (the angle made by the emergent ray with the direction of the incident ray) for red light, for a ray undergoing a single internal reflection inside the drop. The refractive index of water for red light is $n_r = 1.329$.

2) A short-sighted person takes off his glasses and observes a fixed object through them, while moving the glasses away from his eyes. He is surprised to see that at first the object appears smaller and smaller but, as he continues to move the glasses, it subsequently appears larger and larger. Give a quantitative explanation for this observation.

3) Consider the interference pattern of light with wavelength λ from a three-slit apparatus illustrated below. Assume that the openings of the individual slits are the same ($\leq \lambda/2$). At what value of θ will one observe the first principal maximum? What is the intensity at this maximum, if I_0 is the intensity of light incident on the slits?

4) An invar sphere, of 10.1 cm diameter, does not go through a cast iron ring of 10 cm internal diameter at room temperature (25^oC). To what temperature should both the ring and the ball be heated so that it just passes through, if the coefficient of linear thermal expansion for invar and cast iron are 1×10^{-6}K^{-1} and 1.1×10^{-5}K^{-1} respectively?

5) During terminal fall, some spherical rain drops coalesce to form a bigger water drop which attains a terminal velocity four times that of the small drops. Calculate the number of small drops which have coalesced to form the bigger drop.

6) A cube of edge length 0.1 m (in air) and made up of a material with bulk modulus 10^{10} N/m^2, is immersed in water to a depth of 10 km. Calculate the loss of weight of the object.

7) While 1 liter of an ideal gas adiabatically expands to 10 liters, its temperature falls from 527^oC to 47^oC. Determine the atomicity and degrees of freedom of the gas molecules. Use $\log_{10}2 = 0.3010$.

8) Two metal spheres A and B, of mass 50g and 100g, respectively, are suspended vertically by two cords, each of length 2m. Initially the spheres just touch each other with their centers lying in a horizontal line. Sphere A is pulled to one side in the plane of the hanging cords to a height 5cm and released from rest. After swinging down it collides elastically with the sphere B. Find the maximum height to which the sphere A will rise first time after collision.

9) A star of mass M_s is moving in a circular orbit about the center of a galaxy with a radius of 25000 light years and a period of 17×10^7 years. A planet of mass $M_p \ll M_s$, moving in a circular orbit about the star with a radius of 10 light hours, has a period of $375\sqrt{3}$ years. Assume that the gravitational force of the galaxy on the star can be calculated by assuming that the entire mass of the galaxy is at its centre. If the galaxy can be considered to consist of stars of equal mass M_s, estimate the number of stars in the galaxy.

10) A particle is acted on by a force $\vec{F}(t) = \vec{a} + 2t\vec{b}$ where $\vec{a}$ and $\vec{b}$ are constant vectors perpendicular to each other. Initially, at $t = 0$, the momentum of the particle, $\vec{p}_0$, is directed opposite to $\vec{a}$. Find the momentum at a later instant when it is parallel to $\vec{b}$.

11) Show that certain lines in the spectrum of singly ionized helium agree in frequency with some lines in the hydrogen spectrum. Give three examples.

12) Find the de Broglie wavelength of a thermal hydrogen atom at a temperature $300K$. Will such atoms be diffracted by crystals? Give reasons.

13) Hydrogen atom in its ground state is excited by means of a monochromatic radiation of wavelength $970.6\mathring{A}$. How many different wavelengths are possible in the resulting emission spectrum? What is the longest wavelength among them?

14) Gold $^{198}\mathrm{Au}_{79}$ undergoes β^- decay to an excited state of $^{198}\mathrm{Hg}_{80}$. If the excited state decays by gamma emission with energy 0.412, what is the maximum energy of the electron emitted in the decay? Given: Mass of $^{198}\mathrm{Au}_{79} = 197.968225u$; Mass of $^{198}\mathrm{Hg}_{80} = 197.966752u$.

15) A 5 mH inductor is connected in series with a 5 ohm resistor and a battery. When the current through the resistor is 1 A, the battery is switched off. Find the time at which the voltage across the resistor drops to 1 V.

16) A pith ball of mass m and positive charge q hangs at the end of a string of length l, initially held vertical and parallel to an infinite plane of positive charge density σ. The pith-ball is then released, keeping the other end of the string fixed. Find the maximum height to which it rises, assuming the string remains taut.

17) A rod of mass m, length l, and resistance R moves on a pair of horizontal frictionless rails which are perpendicular to the rod. The rails have zero resistance and are connected at one end by a conductor, so as to make a rectangular conducting loop with the rod as one of its sides. A vertical magnetic field B passes through this loop. The rod is kicked with initial speed v_0. Find the time at which the speed of the rod drops to half its initial value.

18) A sinusoidal vibrator, which induces transverse vibrations, is attached to one end A of a string. The other end of the string runs over a frictionless pulley at B, and is stretched by a bucket of sand of mass m. The vibrator along with the string from A to B is on an immovable inclined plane with angle of inclination $\theta = 45°$, as shown in the figure. The separation between A and B is 1.2 m, the linear density of the string is 1.6 g/m, and the frequency of the vibrator is fixed at 120 Hz. The amplitude at A is small enough for that point to be considered a node. A node also exists at B. What mass m allows the vibrator to setup the fourth harmonic on the string? Suppose a hole is now made at the bottom of the bucket through which the sand starts to escape. What fraction of the original mass of sand would have escaped when the tenth harmonic is setup in the string?

19) The number density n_0 of conduction electrons in pure silicon at room temperature is about 10^{16} m^{-3}. We want to increase this number by a factor of a million (10^6) by doping the silicon lattice with phosphorous. What fraction of silicon atoms should be replaced with phosphorous atoms? Assume that at room temperature every phosphorous atom donates its extra electron to the conduction band. Also assume the density of silicon to be 2.33 g/cm^3, molar mass of silicon is 28.1 g/mol and the Avogadro number is 6.02×10^{23} mol^{-1}.

20) You are given two circuits as shown in the figures. Identify the logic operation carried out by each of them.