2006-2007 Physics Olympiad Preparation Program

– University of Toronto –

We continue the competition for the best problems created by our POPTOR contestants. Name your self-made problem as "My Problem", and mail this problem and its solution on a separate sheet of paper along with solutions of the POPTOR problems. You may send us any number of problems, but only self-made and unique will be considered. Authors of the best problems will be awarded during the POPTOR Weekend.

Problem Set 4: Optics and Waves

Due February 5, 2007

Problem 1

Light, or electromagnetic wave, carry momentum and hence exerts pressure on the surface of incidence. Depending on the absorption factor of the surface, the pressure may be greater or less. If we treat the electromagnetic radiation as a beam of photons, the pressure depends on whether the collision between the photon and the surface is a perfectly elastic or non-elastic. The pressure, produced by molecules of a gas on the walls of the container, has a similar nature, as a pressure of photons on the surface. The intensity I of a light beam is an average power passing through the unit area, perpendicular to the beam. The light pressure P is related to the intensity as: $P = k\,I\,/\,c$, where, k is the absorption factor; and c is the speed of light. $k = 2$ for the totally reflective surface normal to the beam of photons.

(a) Determine the value of k for the totally absorbing surface (black body).

Lasers have been used to suspend spherical glass beads in the Earth's gravitational field. The laser is the source of photons with one frequency (coherent radiation). The momentum p of the photon and its energy E are related as: $p = E\,/\,c$.

(b) A black bead has a mass m and a density ρ. Determine the radiation intensity needed to support the bead.

(c) If the beam has a radius r, what is the power required for this laser?

Problem 2

Light passes from air into flint glass with index of refraction n.

(a) What angle of incidence must the light have if the component of its velocity perpendicular to the interface is to remain constant?

(b) Can the component of velocity parallel to the interface remain constant during refraction?

Problem 3

A ball is dropped at t = 0 from rest 3.00 m directly above the vertex of a concave mirror that has a radius of curvature of 1.00 m and lies in a horizontal plane.

(a) Describe the motion of the ball's image in the mirror.

(b) At what time do the ball and its image coincide?

Problem 4

A photoelectric effect is a process of emanation of an electron from the surface of a metal after the absorption of a photon with energy enough to make an electron free with some initial kinetic energy. The minimum energy needed to release the electron with zero kinetic energy is called the work function of the material of the surface. Electrons in the photoelectric efffect are called the photoelectrons.

A light source emitting radiation at 7.00 × 1014 Hz is incapable of ejecting photoelectrons from a certain metal. In an attempt to use this source to eject photoelectrons from the metal, the source is given a velocity toward the metal.

(a) Explain how this procedure produces photoelectrons.

(b) When the speed of the light source is equal to 0.280c, photoelectrons just begin to be ejected from the metal. What is the work function of the metal?
(c) When the speed of the light source is increased to 0.900c, determine the maximum kinetic energy of the photoelectrons.

Problem 5 (experimental)

For this experiment you will need a water tank, a timer, a ruler, thoroughness and patience.

1) Use a method of dimensions (or units) to determine the relationship among the speed c of propagation of waves in the water tank, the acceleration due to gravity g, and the depth H of water in the tank. This method gives a formula without exact dimensionless constants that may also exist in the function $c(g, H)$. Hint: there are no other physical quantities, except g and H, in the formula. Show your work and the obtained formula.
2) Perform a number of experiments with waves varying the depth of water in the tank and measuring quantities necessary to calculate the speed of propagation of the waves. Hint: Try to produce the waves with approximately same frequency.
   Organize results of your measurements in the form of a table.
3) Determine the value(s) of constant(s) in the formula based on the performed experiments.
4) Show the final formula for the function $c(g, H)$.