UNIVERSITY OF TORONTO
Faculty of Arts and Science

Term Test 3

PHY140Y

Duration - 2 hours

24 February 2000

The only allowed aids are hand-held calculators and an attached appendix of formulae. Answer BOTH sections. Show all derivations, and justify each significant step in your answer.

Section A (20%)

Each question is of equal value. Answer all questions.

1. If the force of gravity between two masses were to behave like $r^{-(2+\delta)}$, where r is the separation of the two masses, what effect would this have on Kepler's third law.
2. A spinning top appears very stable. Why? Give at lease one other example of a rotating system with similar properties.
3. What gives rise to tidal forces? Are they unique to gravity?
4. What is the **work function** of a metal?
5. Describe Compton scattering and explain its significance to the development of our modern ideas about the photon.

Section B (80%)

Answer any 4 of the 6 questions. Each question is of equal value.

1. Choose one of the two following topics and write a short ($\sim$ 500 word) essay on it. Structure your answer and include a brief outline of your work! A "stream-of-consciousness" response will not receive full marks. Your answer should introduce the topic, flesh out the details and then conclude with your own perspective.

   (a) Discuss the observations and experiments that led to a "breakdown" in the classical description of black body radiation.

   (b) The conservation of angular momentum in the absence of torques is a powerful principle that can be used to understand everything from the behaviour of atomic systems to galactic motion. Using a few example systems, show how we take advantage of this in day-to-day life.

2. A molecule can be approximated as a uniform rod of length $l = 2.0 \times 10^{-8}$ m and mass $M = 2.0 \times 10^{-25}$ kg. It is polarized – ie, it has a concentration of positive electric charge $Q_+ = 1.0 \times 10^{-17}$ C at one end of the molecule, and a concentration of negative electric charge $Q_- = -2.0 \times 10^{-17}$ C at the other end, as illustrated in Fig. 1. There is also a horizontal, uniform electric field of $\vec{E} = 2.0$ MV/m, oriented as shown in Fig. 1.

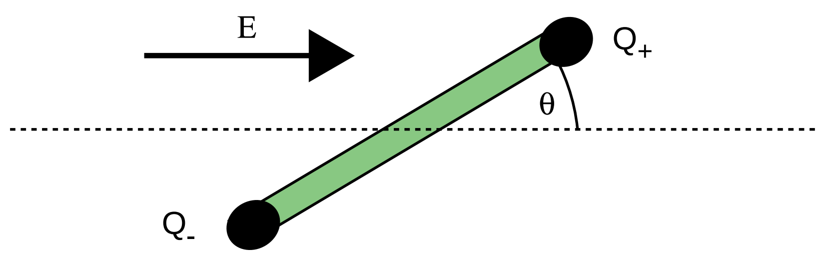

Figure 1: A sketch of a molecular dipole (Question 2).

   (a) Suppose that the molecule is constrained to only rotate about an axis that is out of the plane of the figure. What is the torque acting on the molecule when it is oriented at an angle θ?

   (b) Describe qualitatively the motion of the molecule. What is the equation of motion for the molecule?

   (c) Suppose the molecule is released from rest (but still constrained to rotate about the axis) with an initial angular orientation θ_0. What is the equation for the subsequent motion?

   (d) Now suppose the molecule is released from rest as in the previous question, but it is no longer constrained to rotate about the axis (ie., its centre of mass is now allowed to move). What is the subsequent motion? Be quantitative.

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3. We have a novel particle detector that is able to sense the photons that are produced when a particle travels faster than the speed of light would travel in a material. The photons are produced in a narrow cone around the particle's path through the material and are then detected in a device that employs the photoelectric effect. See Fig. 2.

   (a) The photon's pass through a window and are absorbed in a cesium plate. The plate has a work function of 2.1 eV. What is the maximum wavelength of a photon that will generate a photoelectron?

   (b) The cathode plate is held at a voltage $V = 1.0$ kV, relative to a screen that is 2.0 mm from the edge of the plate. Any electron that is produced (a "photoelectron") will be accelerated by the electric field. For a photoelectron produced by a photon with a wavelength of 300 nm, what is the energy of the photoelectron when it reaches the screen?

   (c) If we have $R_p = 1.0 \times 10^6$ particles per second passing through the detector, with each particle producing on average 20 photons of Cerenkov radiation, what is the current flowing from the photocathode to the screen? You can assume that each photon will generate a photoelectron.

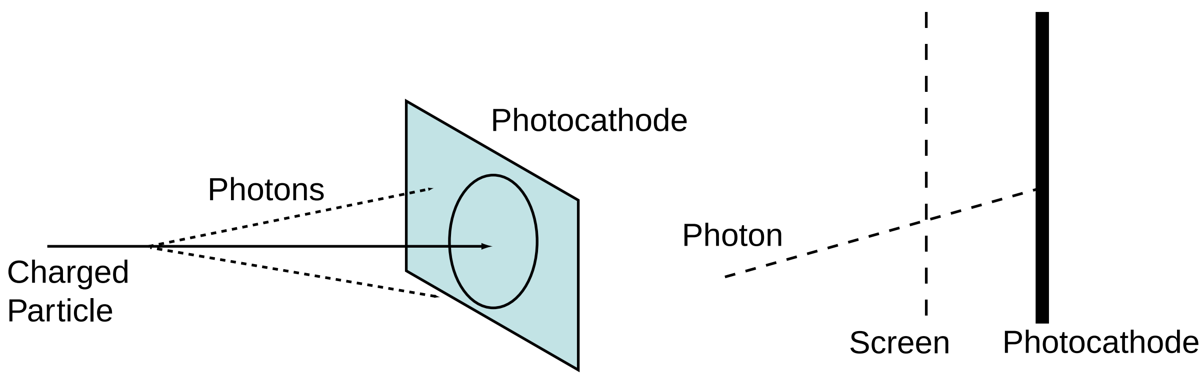

Figure 2: The sketch on the left shows a Cerenkov radiation detector illustrating how the Cerenkov photons come off the particle and are detected by a planar photocathode. The sketch on the right is a close-up of the photocathode, showing the metal screen that is held in front of it (the photons can pass easily through the screen).

4. Let's play some inter-planetary baseball.

   (a) A baseball is thrown on the Earth's surface at a speed of 160 km/h. If it is thrown from the mound of a baseball diamond to home plate 20 m away such that it crosses home plate at the same height that it was released by the pitcher. What is the maximum vertical deflection of the baseball's trajectory? You can assume that the curvature of the Earth is negligible.
   (b) Suppose we were playing a baseball game on a small, spherical asteroid, and we had the same sort of throwing arm. The mass density of the asteroid is $\rho = 2.5$ kg/l. What is the radius of the asteroid if such a 160 km/h throw places the baseball in uniform circular orbit?
   (c) What is the total energy of the baseball in that case?
   (d) If a batter "pops-up" this ball in a purely vertical direction, what is the maximum speed of the struck ball as it leaves the bat such that the ball will return back to the asteroid?
   (e) If the batter hits the ball at 45° from the vertical direction with this maximum speed, describe the resulting motion (an equation is not nececssary, but a cogent explanation is required).

5. Two skaters, each of mass 50 kg, approach each other on parallel paths separated by 3.0 m. They have equal and opposite velocities of 10 m/s. The first skater carries a long light pole, 3.0 m long, and the second skater grabs one end of it as she passes (we can assume the ice is frictionless).

   (a) What is the motion of the two skaters? Describe it quantitatively.
   (b) By pulling on the pole, the skaters reduce their separation to 1.0 m. What is their motion then?
   (c) What is the kinetic energy of the two-skater system in part a) and part b)?

6. A coaxial cable (like the RG-58 cable you use for TV signals) consists of a circular wire with a radius $r_w = 0.5$ mm, followed by an insulator of radius $r_s = 5.0$ mm, followed by a metal sheath with a thickness $r_m = 0.5$ mm. The whole thing is covered with plastic, but we don't need to worry about that. Let's look at the electric properties of this cable.

   (a) If a charge $Q_w = 2.0$ nC is placed on the inner wire and a charge $Q_m = -2.0$ nC is placed on the outer sheath of a length of cable 2 m long, what is the charge density in the wire and in the metal sheath?
   (b) Using Gauss's Law, calculate the electric field in between the inner wire and the metal sheath.
   (c) Calculate the electric potential difference between the inner wire and the sheath.
   (d) What is the capacitance per unit length of the cable.