Name: **Student No.:**

Qualifying Exam
Department of Physics and Astronomy
Michigan State University
January 9, 2007

Put your NAME on every sheet of this 12 problem Exam –NOW

You have 3 hours to complete the 12 problems on this exam. Show all your work! Unsupported answers are not likely to earn the full credit and may even earn no credit at all. A partial credit may be earned for correct procedures, even if the correct answer is not reached. Answers must be in the spaces provided. The BACK of the problem sheet may be used for lengthy calculations. Do not use the back of the preceding sheet for this purpose!

You may need the following constants:

Speed of light in vacuum:	$c = 3.00 \times 10^8\,\mathrm{m/s}$
Boltzmann constant:	$k = 1.38 \times 10^{-23}\,\mathrm{J/K}$
Planck's constant:	$h = 6.63 \times 10^{-34}\,\mathrm{J\,s} = 4.14 \times 10^{-15}\,\mathrm{eV\,s}$
	$hc = 1240\,\mathrm{eV\,nm}$ $\quad$ $\hbar c = 197\,\mathrm{MeV\,fm}$
Gas constant:	$R = 8.31\,\mathrm{J/(K\,mol)}$
Permittivity of free space:	$\epsilon_0 = 8.99 \times 10^9\,\mathrm{C^2/(N\,m^2)}$
Permeability of free space:	$\mu_0 = 4\pi 10^{-7}\mathrm{N\,s^2/C^2}$
Atomic mass unit:	$1\,\mathrm{u} = 1.661 \times 10^{-27}\,\mathrm{kg} = 931.5\,\mathrm{MeV/c^2}$
Electron mass:	$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$

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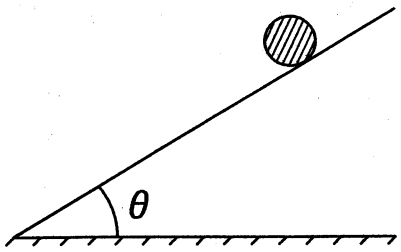
1. A uniform steel ball of mass M and radius R (and hence moment of inertia $\frac{2}{5}M\,R^2$) rolls without slipping down a ramp that makes an angle θ with the horizontal. The ball starts from rest.

   (a) [4 pts] Calculate how far the ball has travelled as a function of time.

   (b) [3 pts] Calculate the component of force on the ball due to the ramp in the direction perpendicular to the ramp.

   (c) [3 pts] Calculate the component of force on the ball due to the ramp in the direction parallel to the ramp.



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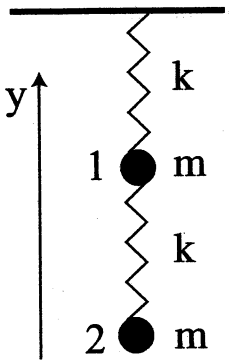
2. A small object 1 of mass m is suspended from a fixed support by a massless spring with spring constant k. A second object 2 of the same mass is suspended from the first by an analogous spring.

   (a) [4 pts] Write down the equations of motion for displacements y_1 and y_2 of the two objects from their equilibrium positions.

   (b) [6 pts] Find the normal frequencies of oscillation for the system.



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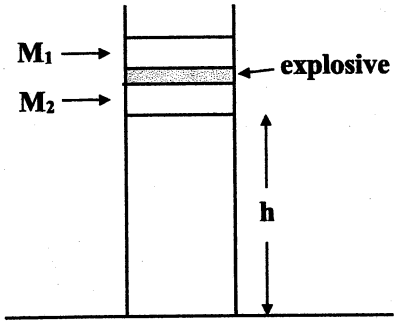
3. [10 pts] Two flat pistons, of masses M_1 and M_2, are attached by a thin layer of explosive plastic. The pistons are momentarily at rest in the interior of a long smooth vertical tube (pipe) near the surface of the earth. At time $t = 0$ the layer of plastic explodes, leaving the pipe undamaged, but imparting instantaneously total kinetic energy E to the two pistons. Find the time at which the lower of the two pistons, initially at elevation h, hits the ground. (Ignore air resistance and friction against the pipe, but account for the effects of gravity.)



4. A fish swims 4 m below the surface of a clear, freshwater lake ($n_{\text{water}} = 1.33$).

   (a) [4 pts] When the fish looks upward during a bright day, it sees images of objects in the air ($n_{\text{air}} = 1.00$) above the surface. However, for some more lateral directions, the fish does not see the objects outside of water but instead just a silvery water surface. If the collection of directions for which the fish can see objects in the air can be described by a cone, what is the cone angle?

   (b) [6 pts] A hawk is flying 10 m above the water surface and directly above the fish. Determine the apparent depth of the fish beneath the water surface, when viewed by the hawk?

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5. An infinitely long cylinder of radius R has a uniform volume charge density $\rho > 0$. Find the electric field (both magnitude and direction)

   (a) [4 pts] at a point outside the cylinder and

   (b) [6 pts] at a point inside the cylinder.

6. [10 pts] The magnetic flux through a metal ring varies with time t (in seconds) according to the expression below:

$$\Phi = 3(a\,t^3 - b\,t^2)\ \text{Tesla}\,\text{meter}^2\,,$$

where

$$a = 2\,\text{sec}^{-3} \quad \text{and} \quad b = 6\,\text{sec}^{-2}\,.$$

The resistance of the ring is 3 ohms. What is the maximum current induced in the ring during the time interval from $t = 0$ sec to $t = 2$ sec?

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7. [10 pts] A neutral pion with rest energy of 135 MeV and total energy of 300 MeV is travelling in the $+z$ direction. It decays into two massless photons ($\pi^0 \rightarrow \gamma + \gamma$) which happen to go in the $+z$ and $-z$ directions. Find the energy of each photon.

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8. The work function for Zinc is 4.3 eV.

   (a) [5 pts] What is the maximum wavelength of light that can eject electrons from Zinc?

   (b) [5 pts] If light of wavelength 254 nm shines on the metal, what will be the kinetic energy of the ejected photoelectrons?

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9. $^{158}_{65}$Tb can decay via the weak interaction.

   (a) [3 pts] Describe the changes that would take place in the β^- decay and in the β^+ decay of $^{158}_{65}$Tb (i.e. what would get transformed or produced) using reaction notations of the form $B \rightarrow C + d + e$.

   (b) [7 pts] Determine whether β^- decay of $^{158}_{65}$Tb is energetically allowed. Do the same for β^+ decay.

   Useful information: Data tables provide masses of neutral atoms, including electron masses. The atomic mass of $^{158}_{65}$Tb is 157.925411 u. The atomic mass of $^{158}_{64}$Gd is 157.924099 u. The atomic mass of $^{158}_{66}$Dy is 157.924403 u. The mass of an electron is approximately 5.61×10^{-4} u. Assume that neutrinos have negligible mass and that any effects of electron binding energies can be ignored.

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10. (a) [5 pts] The ground state energy of an electron trapped in a one-dimensional infinite potential well of width L is 3 eV. If the width is doubled, what is the ground state energy?

    (b) [5 pts] The electron is excited from the ground state to the first excited state. Does this increase, decrease, or have no effect on the probability of detecting the electron in a small finite-length interval near the well edge? Explain and, if you can, quantify your answer in terms of a factor.

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11. [10 pts] A salesman presents a homeowner with a sales brochure that promotes the benefits of heating one's home with a heat pump that extracts heat from the outside air and deposits it into the interior of a home. In the brochure, it is claimed that the heat pump requires only 1 kW of electrical power in order to supply 20 kJ of heat per second to the interior of a house when the indoor temperature is 20 °C and the outside temperature is -15 °C. Is the brochure's claim consistent with the second law of thermodynamics? (Give your answer. Show your calculations that indicate why your answer is correct and explain those calculations!)

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12. [10 pts] The magnetic moment of a proton (spin $\frac{1}{2}$) is 1.4×10^{-26} J/T. Estimate the magnetic field (in tesla) required to produce 90% alignment of protons in a sample of paraffin (which contains many protons) at temperature of 0.01 K.