BPT FRQ Problems 2026

Society for Physics Students, Berkeley

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1. Not for Those In Glass Houses

Imagine that you have a rock, with a point mass m.

(a) If you throw this rock from the ground at an angle θ above the horizontal, with an initial velocity v, what is its initial horizontal velocity? Give your answer in terms of v and θ.

(b) If you throw the rock while on flat ground, calculate the total amount of time the rock will spend in the air before first contact with the ground. Assume that the gravitational acceleration is g.

(c) Suppose the rock is subjected to a constant horizontal acceleration a_0 in the forward direction. The vertical motion remains unchanged. Find the horizontal velocity $v_x(t)$ as a function of time.

(d) Calculate the the total horizontal distance traveled by the rock with all the variables defined above.

2. Let's get this par-TEA started

Suppose we have two identical cups. Cup A contains hot tea at $T_h = 100°\text{C}$, and Cup B contains pure water at $T_c = 0°\text{C}$. Both cups contain the same mass of liquid and have the same constant heat capacity C. We wish to heat the pure water in Cup B using the thermal energy in Cup A. The two liquids cannot be mixed. Assume that the cups have negligible heat capacity, and that no heat escapes into the environment.

(a) If Cup A and Cup B are placed in thermal contact until they reach equilibrium, what is the final temperature of the pure water?

(b) Suppose we instead divide the hot tea from Cup A into two equal portions. We first bring the first portion into thermal contact with Cup B until equilibrium is reached, then remove it. We then bring the second portion (still at 100°C) into contact with Cup B. What is the final temperature of the pure water? Explain why this result is different than the result in part (a).

(c) If we divide the hot tea into n equal portions and repeat this sequential process - bringing each portion into contact with Cup B one by one and removing it after equilibrium - the final temperature of the pure water approaches a limit as $n \to \infty$. Calculate this upper limit.

(d) Even in the limit $n \to \infty$, why is it impossible to heat the pure water to 100°C using this method?

3. Ice-olation

Suppose that Finn is stranded in the middle of a frictionless ice lake, on a cart which is at rest. Bolted to the cart is a snow machine and a cylindrical tank full of snow. Finn's snow machine is connected to the tank of snow, and begins to expel snow continuously at speed u. We call Finn, the cart, and the bolting mechanisms the system. Assume that the snow machine can eventually empty the tank. We neglect air resistance.

(a) Let the total initial mass of the system be M_i. The snow has mass density ρ. Let the diameter and height of the tank be D and L, respectively. Determine the combined mass of the system once the tank is emptied. Express in terms of M_i, D, ρ, and L, and any physical constants.

(b) The snow machine is initially oriented so that the snow expels parallel to the ground. Determine the final speed of the cart, v_f, when the tank is empty. You may use the following formula, commonly known as the rocket equation, which assumes no external forces:

$$\Delta v = v_e \ln \frac{m_0}{m_f}$$

Δv is the change in speed, v_e is the exhaust speed, m_0 is the initial mass of the system, and m_f is the final mass of the system. Express your answer in terms of u, ρ, D, M_i and L.

(c) Hypothetically, if the snow machine now expels snow at twice the rate of mass per second and with half of the amount of initial snow in the tank, starting from rest, will Finn go faster, slower, or the same speed as your answer in part (b) when the tank is empty?

(d) Finn reaches walkable land, however he has to wait for the cart to come to a stop before exiting. If the coefficient of friction between the cart and the walkable land is μ, how long does it take for the cart to come to a stop? Express your answer in terms of u, μ, M_i, D, L, and any physical constants.

4. Escape Room: Cosmic Edition

In 1783, the English philosopher and clergyman John Michell wondered if there could be a star massive enough such that no light could escape it, rendering it invisible. Today, we know with certainty that these dark stars, now called black holes, exist, and that they are created when stars collapse under their own gravity at the end of their life cycle.

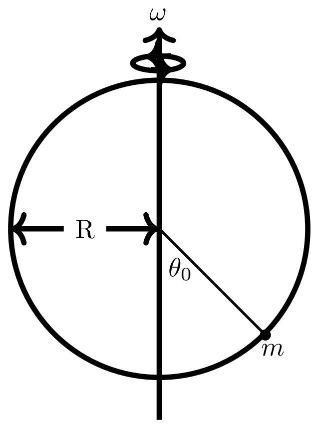
+2 correct .

(a) Michell realized that black holes could be detected if they were part of a binary system. Imagine a system comprising a black hole with mass M_d and a visible star with mass m_v, where $M_d \gg m_v$ such that the orbit is approximately centered around the black hole. Derive an expression for M_d in terms of the orbital radius r, period T, and the gravitational constant G.

(b) As a photon climbs out of the gravitational well of the star, it loses energy. Explain why an observer at a great distance would see the light shift toward the red end as the star's radius r approaches r_s.

5. Bead it!

A bead of mass m is attached to a ring of radius R and mass M. The ring is rotating around a rotation axis along its diameter with a constant angular velocity ω. The ring and rotation axis are in the same plane. Assume that the bead is acted upon by gravity mg, and that there is no friction between the bead and the ring. Let the angle $\theta = 0$ on the ring be defined as the bottom-most point.



(a) If the bead starts off very close to the bottom of the ring, and $\omega \geq \sqrt{g/R}$, what is the stable equilibrium angle θ_0?

(b) In the rotating reference frame of the bead, there exists an additional "force" felt by the bead. Write down this effective potential energy in terms of ω, g, R as a function of θ.

(c) The bead will tend to oscillate around the point you found in part (a). What is the frequency of this small oscillation? On small timescales, the effect of friction is negligible.

6. Resistance is Futile

A highly elastic, perfectly circular loop of conductive wire is placed in a uniform magnetic field B that points perpendicular to the plane of the loop. The wire has a constant total volume V and is made of a material with uniform resistivity ρ. A system stretches the loop outward, increasing its radius at a constant rate v; the loop radius as a function of time is $r(t) = r_0 + vt$.

(a) As the wire stretches, it gets thinner and longer, but its total volume V remains constant. Find the electrical resistance of the loop $R(t)$ as a function of its radius $r(t)$. Make the assumption that the radius is much smaller than the circumference of the ring.

(b) At a high level, Faraday's Law of Induction states that when the total magnetic flux through a loop (magnetic field perpendicular to the loop · area of the loop) changes, a current with magnitude proportional to the flux is generated in the loop. Lenz's Law states that the direction of the magnetic field generated by this current has the effect of opposing the change of the magnetic flux. Conceptually, why must this be the case?

(c) In this problem, the increasing area of the wire loop leads to a change in magnetic flux through it, thereby inducing a current. After performing the full Faraday's Law calculation, one can find that the effective voltage driving the induced current is $\mathcal{E} = 2\pi B v r(t)$. Calculate the magnitude of the induced current $I(t)$ in the loop. Does the current increase, decrease, or stay the same as the loop expands over time?

(d) Calculate the magnitude of the total magnetic force acting on the wire loop. Does this force assist the system in stretching the wire, or oppose it?

7. Neutri-no Way!

The CUORE experiment is attempting to detect Neutrinoless Double Beta Decay ($0\nu\beta\beta$) using an array of nearly 1000 TeO_2 crystals. Each crystal is cooled to about 10 mK, and attempts to detect a tiny temperature rise caused by energy deposits released during the decay. Neutrinoless Double Beta Decay, if observed, would show that neutrinos are their own antiparticles. Cool!

(a) Nuclear decays often release energies on the scale of 1 MeV. The conversion is $1\text{eV} = 1.602\times10^{-19}$J. Classically, to the nearest order of 10, to what speed would a proton be accelerated to from rest, if it had all the energy from one of these decays? A proton has mass around 1 amu, where $1\text{amu} = 931.5\text{MeV}/c^2$

(b) When a neutral Sodium-22 isotope undergoes typical beta-plus decay, the end products are a neutral Neon-22 isotope, the remaining electron from the Sodium-22, a positron (which has the same mass as an electron), and a neutrino (which is nearly massless). If the electron mass is $5.48 \cdot 10^{-4}$ amu, the mass of neutral Sodium-22 is 21.994 amu, and the mass of neutral Neon-22 is 21.991 amu, how much energy is released by this process?

(c) Each TeO_2 crystal in the CUORE detector acts as a bolometer, also known as a heat detector. When an energy of $E = 2.528$ MeV is deposited, the expected amount of energy released for ^{130}Te double-beta decay, the temperature of the crystal rises by $\Delta T = E/C$, where C is the heat capacity. Assuming that $C = 2 \cdot 10^{-9}$ J/K, calculate the resulting temperature rise.

(d) Explain briefly why operating at millikelvin temperatures makes this measurement feasible.

(e) In theories of $0\nu\beta\beta$, the inverse half-life is related to the effective Majorana neutrino mass $m_{\beta\beta}$ by

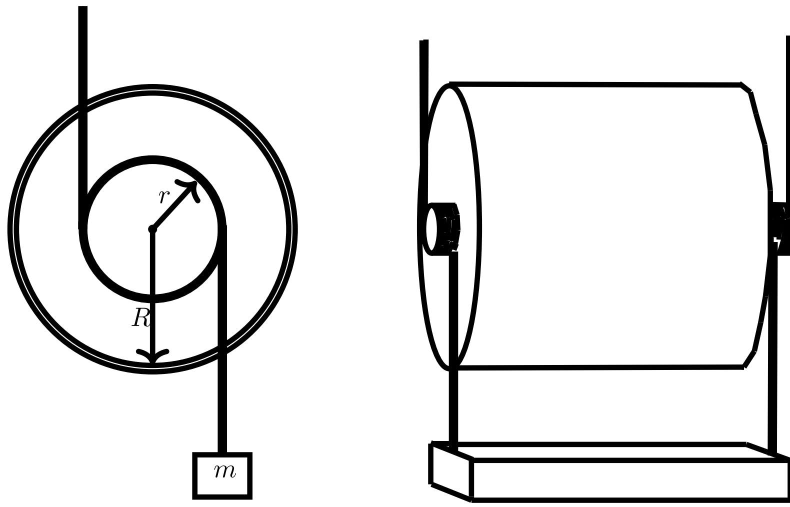
$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}|M^{0\nu}|^2\frac{m_{\beta\beta}^2}{m_e^2}$$

CUORE reports $T_{1/2}^{0\nu} > 3 \cdot 10^{25}$ yr, while another experiment achieves $T_{1/2}^{0\nu} > 3 \cdot 10^{26}$ yr. By what factor does the stronger result improve the upper bound on $m_{\beta\beta}$?

(f) Identify 2 distinct physical mechanisms that could mimic a signal event, and describe one realistic method that CUORE uses (or could use!) to suppress each.

8. That's How We Roll

A rigid body of mass m with radius $R = 3r$ is connected to two smaller cylinders of radius r extending out of each end. It is supported by two ideal ropes wrapped around the smaller cylinders, as shown in the diagram. The total moment of inertia about its axis of symmetry is well approximated by $I = mR^2$. A block of the same mass m is supported by two other ropes wrapped around the small cylindrical extensions. The ropes do not slip.



(a) Draw extended free body diagrams for the cylindrical object and the block.

(b) Derive an expression for the magnitude of the angular acceleration α of the cylindrical object as a function of the linear acceleration of the block a_{block} and r.

(c) What is the magnitude of the angular acceleration of the cylinder? Express your answer in terms of r, and use $g \approx 10\,\text{m/s}^2$.

(d) What is the tension in each of the lower ropes that are supporting the block? Express your answer in terms of m and g.

(e) Now consider the same setup, but with the rigid rotating object replaced by one with the same small cylindrical extensions of radius r, but a smaller radius for the central cylinder $R < 3r$, so the moment of inertia is now $mR^2 < 9mr^2$. What condition must R satisfy for the block to accelerate downward with magnitude less than g?

9. POV: You're a Planet Getting Cooked by a Main Sequence Star

A blackbody is an ideal object assumed to absorb and emit radiation perfectly, with no reflection or transmission. A distant star is modeled as a blackbody of radius R_s and temperature T_s, whose total flux I_s and peak wavelength λ_s can be measured from Earth.

A planet of radius R_p orbits the star at radius r. The planet absorbs all incident radiation, has negligible internal heating, and radiates uniformly over its entire surface as a blackbody. Its thermal spectrum peaks at wavelength λ_p. The distance from Earth to the system is d, and you may assume $d \gg r$. eYou may use the following equations:

$$F = \sigma T^4, \qquad \lambda_{peak} T = b, \qquad L = 4\pi R^2 F, \qquad I = \frac{L}{4\pi d^2}.$$

where F is the flux at the surface of the object, I is the flux at a distance d, L is the luminosity of the object, and σ, b are constants

(a) Express R_s in terms of I_s, d, λ_s, σ, and b.

(b) Derive an expression for the orbital radius r in terms of I_s, d, λ_p, σ, and b only. Your final answer should not contain R_s, T_s, or λ_s.

(c) Find the ratio of the total flux from the planet to the total flux from the star, both as measured at Earth. Express your answer in terms of R_p and r only.

(d) Considering the ratio found in part (c), briefly explain whether the planet will appear brighter or dimmer if it is closer to the star and why this is physically reasonable.