Review Problems
for
Elementary Physics 41

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Contents

1 Introduction and Instructions

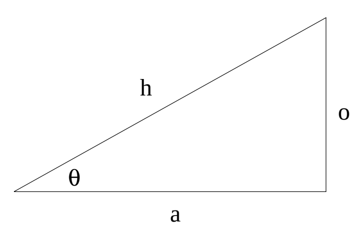
This review guide is NOT sorted or made unique – it is the simple union of all the problems in my problem repository. Some problems that I give "a lot" (such as Maxwell's Equations) may be represented many times. Others may occur only once. To a certain extent this reflects their frequency of occurrence and hence the weight I give to the material being tested. This can be used as a clue for how best to spend your limited study time – if something is here three or four times in various forms it is a good idea to know how to do it. If it is here only once, you *might* get a way without knowing it, although of course you should try not to have to take that sort of risk.

Note well that I *always* make up a new problem or two for just about any exam I give, so this list is not and cannot be totally complete. Still, if you can do all of these problems you are likely to be able to do any of the new problems I make up (or at least do as well as any students on those problems).

This whole course emphasizes problem solving and derivation as a route to a deep conceptual understanding of the material. By the time you can work *all* of these problems *quickly* you will be well on your way to true mastery of the material.

Enjoy!

2 Math Review



1. $$\sin(\theta) =$$
$$\cos(\theta) =$$
$$\tan(\theta) =$$

2. $$\frac{d}{dt}(at^5 + be^{-ct^2} + sin(dt)) =$$

3. Solve for x:
$$ax^2 + bx + c = 0$$

4. Cross product (give magnitude and direction)
$$\vec{A} \times \vec{B} =$$

5. Dot product

$$\vec{A} \cdot \vec{B} =$$

3 Short Answer Problems

6. What is Newton's First Law?

7. What is Newton's Second Law? (Give more than one form for extra credit.)

8. What is Newton's Third Law?

9. What is the *Generalized* Work-Mechanical-Energy Theorem? (Equation only. This is the one that differentiates between conservative and non-conservative forces.)

10. Tommy is working on a physics problem involving energy. "Look," he says, "the total energy of this block is zero at the top of the incline and therefore must be zero at the bottom."

    Sally disagrees. "Impossible. The block is at the *top* of the incline. It has total energy mgH at the top and so its total energy must still be mgH at the bottom."

    Who has a chance of getting the right answer (that is, hasn't made a mistake *yet*, at least)? Explain your reasoning.

11. What is Kepler's First Law?

12. What is Kepler's Second Law? (What physical principle does it correspond to, for extra

credit?)

13. What is Kepler's Third Law?

14. What is Newton's Law for Gravitation? Draw a picture showing the coordinates used, and indicate the value of G.

15. Write the perpendicular axis theorem. Draw a picture to go with it, if it helps.

16. Write the *integral* definition of the moment of inertia of an object. Draw a picture illustrating what "dm" is.

17. When is the angular momentum of a system conserved?

18. A 1 kg hammer falls 3.2 meters (about ten feet) off of a roof and onto your head. Ouch! Assuming that the tool is in contact with your head for around a time $\Delta t \approx 10$ milliseconds before stopping and sliding, what is the average force it exerts on your hapless skull while stopping?

19. Many comets are not bound to the sun – they fall in from infinity, make a single pass by the sun, and then fly out to infinity once again with a positive total energy. What is the

name of this unbound orbit?

20. What are the conditions for an object to be in static equilibrium?

21. Qualitatively sketch $P_{\text{av}}(\omega)$ for a damped, driven harmonic oscillator with resonant frequency ω_0 and $Q = 10$.

22. What is Pascal's principle? A small picture would help.

23. Write the wave equation (the differential equation) for waves on a string with tension T and mass density μ. Identify all parts.

24. What is the so-called "0th Law of Thermodynamics"?

25. What is the 1st Law of Thermodynamics (and what physical principle or microscopic law does it correspond to)?

26. What is the 2nd Law of Thermodynamics? Note that we learned at least five different forms for this law in class – one point of extra credit will be given for each (correct)

additional form past the first one.

27. One measures sound intensity in decibels. What is a decibel? (Equation, please, and define all constants.)

28. What is Bernoulli's equation? What does it describe?

29. What is the Equipartition Theorem?

30. A small boy is riding in a minivan holding a helium balloon that is pulling straight up. The van goes around a corner to the left. Does the balloon swing to the left, still pull straight up, or swing to the right as the van swings around the corner?

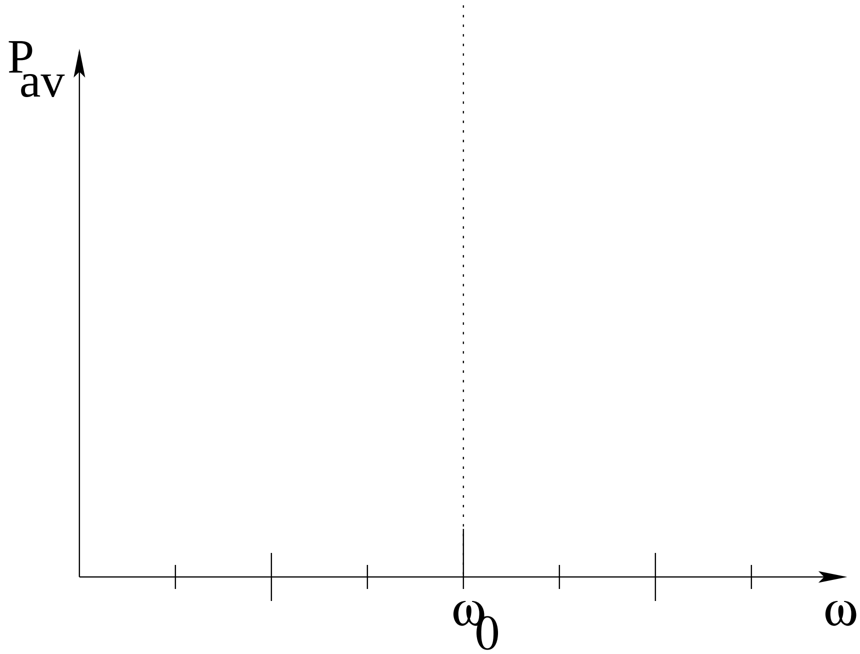
31. What is Archimedes' Principle? (I need equation with associated diagram, but not a full derivation.)

32. A solid ball (A), a ring (B), and a disk (C) roll down a smooth incline without slipping. Rank the order in which they reach the bottom.

33. A ball *rolls* down a rough incline without slipping and then slides up a frictionless hill on the other side (visualize it). Does it go up higher, to the same height, or not as high on the slippery hill?

34. Write the parallel axis theorem. Draw a picture to go with it, if it helps.

35. Sketch two $P_{\mathrm{av}}(\omega)$ curves: one for a damped, driven harmonic oscillator with resonant frequency ω_0 and $Q = 12$ (solid line) *and* one for a damped, driven harmonic oscillator with the same resonant frequence ω_0 but for $Q = 4$ (dashed line). The curves should be drawn to approximately correct proportions to represent the values of Q.



36. What is the Equipartition Theorem?

37. How is the coefficient of performance of a refrigerator defined? (Also give the correct definition of the efficiency of a heat engine for 3 bonus points.)

38. What is the name of the effect or principle that creates lift on airplane wings, causes spinning baseballs to curve, and atomizes perfume and gasoline, all because pressure decreases where a flowing fluid speeds up?

39. State Archimedes' Principle in words. Draw a small picture if it helps.

40. What is conserved (and what isn't) in an inelastic collision?

41. Mr. Hoop and Mr. Disk had a race rolling down a smooth hill without slipping. They started at the top at the same time. Who won? Why? (For a bit of extra credit, where would Mr. Solid Ball have placed if he had raced too?)

42. An Orc throws a 2 kg spear at Frodo Baggins at point blank range, but it is stopped by his hidden *mithril* mail shirt. Assuming that the spear was travelling at 20 m/sec when it hit and that it stopped in 0.1 seconds, what was the average force exerted on the spear by the mail coat (and the hobbit underneath)? Ouch!

43. What is "centrifugal force"?

44. What "force" makes hurricanes spin anticlockwise in the southern hemisphere?

45. What is the "terminal velocity" of an object in free fall in air (explain what it is and why, possibly with an equation, not with a value).

4 Quiz/Hour Exam Problems of Years Past

4.1 Kinematics and Dynamics

4.1.1 Kinematics

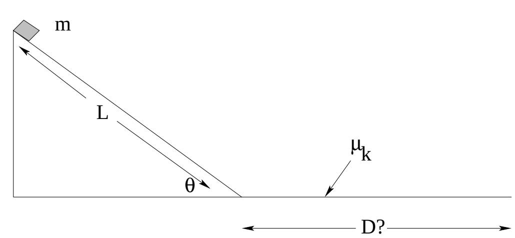
46. A distance of D meters ahead of your car you see a box turtle crossing the road. Your car is traveling at a speed of v meters per second straight at the turtle (along the straight road).

a) What is the *minimum* acceleration your car must have in order to stop before hitting the turtle?

b) How long does it take to stop your car at this acceleration?

(Note: Just this once, I'll give you some hint/suggestions that will save you a point or two. First, **draw a picture of what is going on.** *Always* use figures to visualize motion and connect the given quantities to the variables you need to use. Second, **acceleration is a vector** even in one dimension, so be sure to put a coordinate system on your picture/figure and express your answer with the correct sign in your chosen coordinates. Show all algebraic work. Be neat. Check your units for sanity.

4.1.2 Dynamics

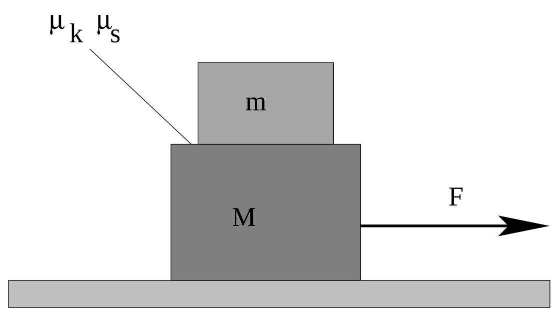


47. A block of mass m slides down a *smooth* (frictionless) incline of length L that makes an angle θ with the horizontal as shown. It then reaches a *rough* surface with a coefficient of kinetic friction μ_k.

a) How long does it take to reach the bottom of the incline?

b) How far D down the rough surface does it slide before coming to rest?

(Note: b) can be answered with or without using the concept of work as you please.)

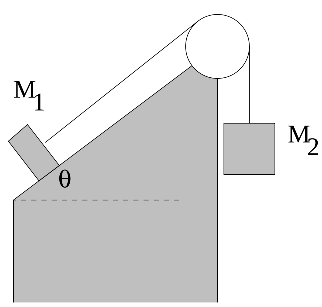


48. A small block of mass m sits on top of a large block of mass M on a frictionless table. The coefficient of static friction between the two blocks is μ_s and the coefficient of kinetic friction between the two blocks is μ_k. A force $\vec{F} = F\hat{x}$ is directly applied to the *lower* block as shown.

a) What is the largest $F = F_{\rm max}$ that can be applied such that the upper block does not slide on the lower block?

b) Suppose that $F = 2F_{\rm max}$ (so that the upper block slips freely). What is the acceleration of each block?

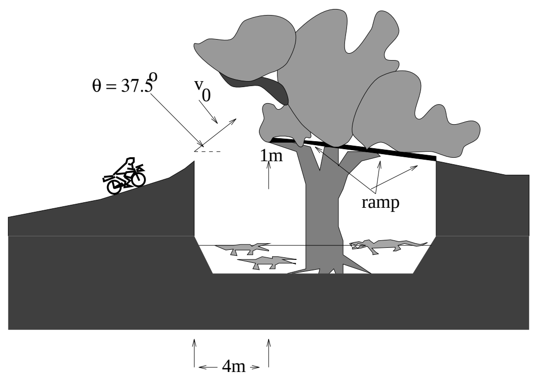
4.2 Work and Energy



49. Two blocks with mass M_1 and M_2 are arranged as shown with $M_1 > M_2$ sitting on an inclined plane and connected with a massless unstretchable string running over a massless, frictionless pulley to M_2, which is hanging over a drop. The two masses are released with M_2 initially a height H above the ground.

a) Find an *algebraic expression* for the angle θ_0 such that the system remains at rest.

b) Suppose $\theta < \theta_0$. How fast is M_2 travelling when it hits the ground (as a function of θ).



50. Evie Kniebel is a stunt woman for a movie is trying to jump a motorcycle across a ditch and land on a special ramp that is built into the branch of a convenient tree. The horizontal gap she must leap to reach the ramp is 4 m. The ramp is vertically 1 m above the lip of the takeoff ramp. The angle of the takeoff ramp is fixed at 37.5° (which just happens to be the angle of a 345 right triangle).

    The "plot" of the movie requires that the ditch be filled with 16 to 20 foot mugger crocodiles imported from the Ganges in India just for this film, as the director is a sucker for realism and doesn't believe in computer generated crocs or latex croc-bots. Feeding them is cheap, however – so far they've dined on Evie's stunt-cousins Evel, Weevel, and Abel Kneibel...

    If Evie jumps even a bit too high, she will wreck on an overhanging branch and the crocs will dine well yet again. If she jumps too low, she bounces back and also becomes crocodile-bait. With what speed v_0 must she take off to complete the jump "just right" (and live to get paid)? Note that you must answer the question algebraically FIRST and only then worry about numbers.

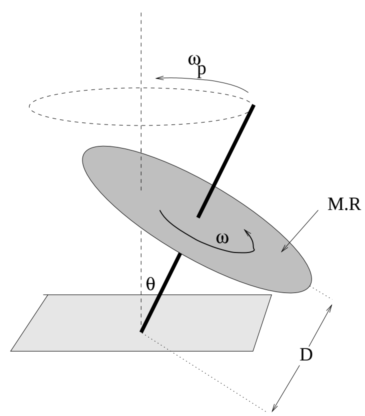
    And you thought physics wasn't useful...

51. A pendulum bob of mass $M = 0.5$ kg is suspended with an Acme Physics String[1] from the roof of a freight car that is accelerating at $a = 1\frac{\text{m}}{\text{sec}^2}$ to the right. The weight is observed to hang at an angle θ with respect to the vertical while this occurs. Use $g = 10\frac{\text{m}}{\text{sec}^2}$.

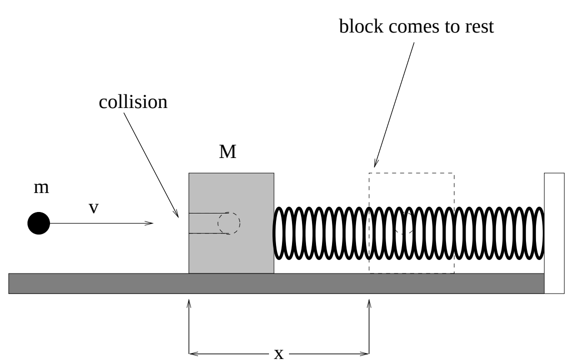
a) Draw a *neat* picture of all of this, labeling all forces, and *derive*:

a) The angle θ. You don't need the number, just the algebraic expression you'd evaluate with a calculator if you had one handy.

b) The tension T in the string. Again, the algebraic expression is fine.



52. A top is made of a disk of radius R and mass M with a very thin, light nail ($r \ll R$ and $m \ll M$) for a spindle so that the disk is a distance D from the tip. The top is spun with a large angular velocity ω. When the top is spinning at a small angle θ with the vertical (as shown) what is the angular frequency ω_p of the top's precession?



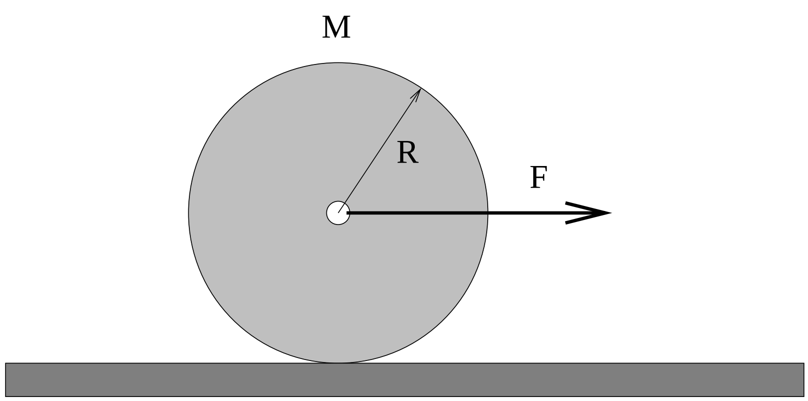
53. A ball bearing of mass $m = 50$ grams travelling at 200 m/sec smacks into a block of mass

[1] Massless and unstretchable, of course...

$M = 950$ gms and sticks in a hole drilled therein. The block is initially at rest on an Acme frictionless table and is also connected to an Acme spring with spring constant $k = 400$ N/m at its equilibrium position (see figure).

a) What is the maximum distance x the spring is compressed by the recoiling ball bearing-block system?

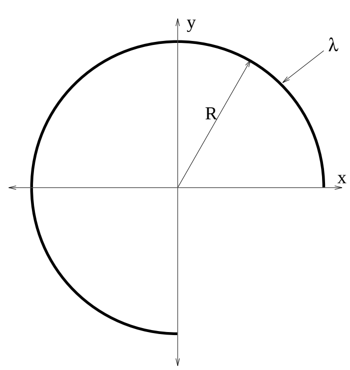
b) How much mechanical energy is lost in the collision (noting that an answer of 'none' is one possibility)?



54. A force $\vec{\mathbf{F}} = 48$ N to the right is applied to the frictionless axle of a wheel made of a uniform disk with mass $M = 4$ kg and radius $R = 10$ cm. It rolls without slipping on a rough table. Find:

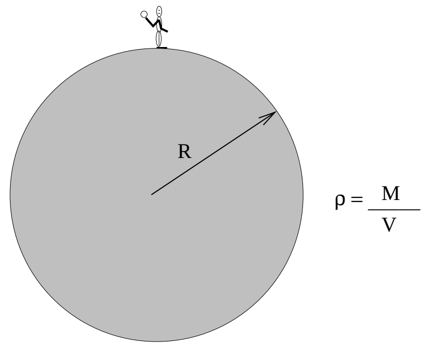
a) the net acceleration of the wheel.

b) The minimum coefficient of static friction μ_s such that the wheel does not slip for this force.

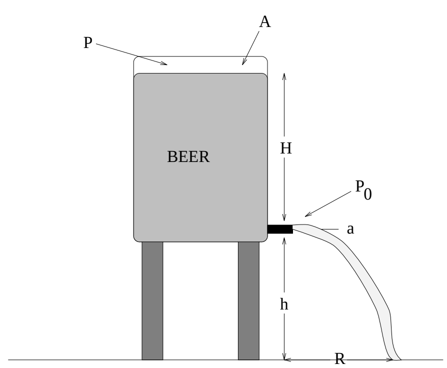


55. Find the center of mass of the 3/4 hoop of wire above. It has a uniform mass per unit

length $\lambda = 10$ grams/meter, and its radius $R = 100$ cm.



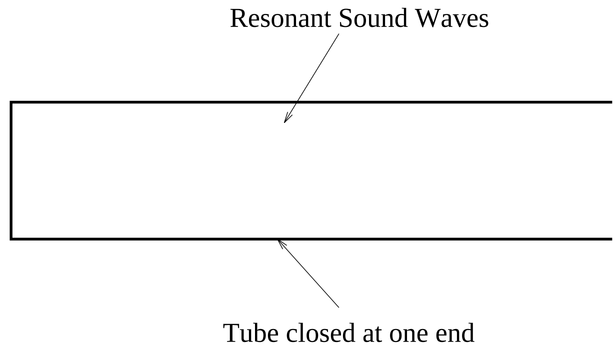
56. Planetary rock has an average density around 10^4 kg/m^3. Assuming that you can throw a fastball around 40 m/sec (nearly 90 mph) what is the approximate radius R of the *largest* spherical planet where you can stand on the surface and throw a baseball away (to infinity)?



57. In the figure above, somebody has pumped a beer keg with a cross sectional area $A = 0.25$ m^2 up to $P = 2$ atmospheres of pressure at the top (1 atm $= 10^5$ Pascals) and pulled the tube off of the tap (which has a cross sectional area of $a = 0.25$ cm^2) at the bottom. The surface of the beer is $H = 50$ cm above the tap at the bottom. Fortunately, the keg is up on a stand $h = 1$ m above the ground, so that you can catch it in a bucket.

a) Where should you put the bucket to catch the beer? (Find R. Don't forget P_0).

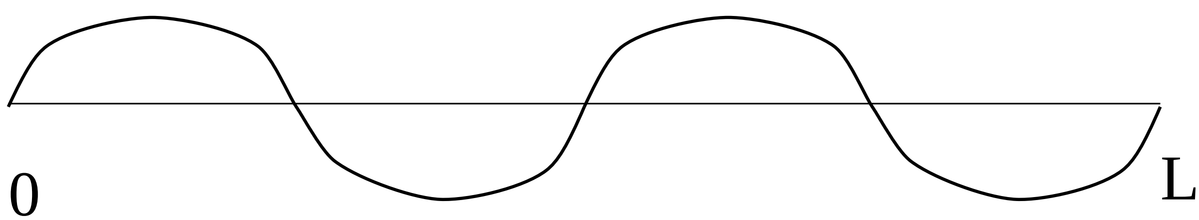
b) How long (approximately) do you have to find a bucket before the beer is all gone?



58. An organ pipe is made from a brass tube closed at one end as shown. The pipe is 3.4 meters long. (Assume that the speed of sound is 340 meters/second). When played it produces a sound that is a mixture of the first, third and sixth harmonic (mode).

a) What are the frequencies of these modes?

b) Qualitatively sketch the wave amplitudes for the first and the third harmonic modes (only) in on the figure, indicating the nodes and antinodes. Be sure to indicate whether the nodes or antinodes drawn are for **pressure/density** waves or **displacement** waves!



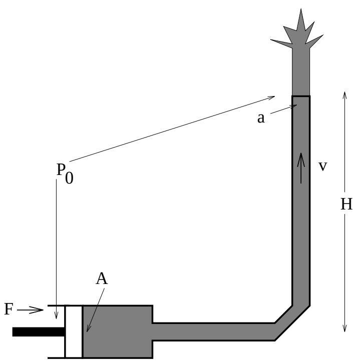
59. A string of total mass M and total length L is fixed at both ends, stretched so that the speed of waves on the string is v. It is plucked so that it harmonically vibrates in its $n = 4$ mode:

$$y(x,t) = A_4 sin(k_4 x) cos(\omega_4 t).$$

Find (derive) the instantaneous total kinetic energy in the string in terms of M, L, $n = 4$, v and A_4 (although it will simplify matters to use k_4 and ω_4 **once you define them**).

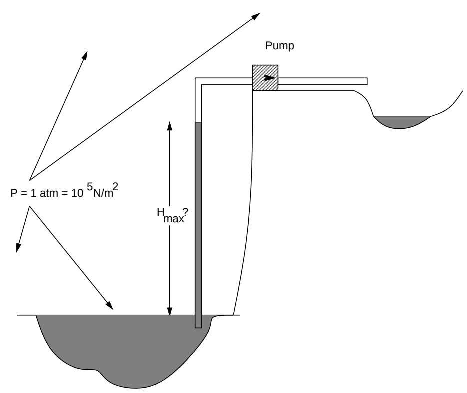
Remember (FYI):

$$\int_0^{n\pi} \sin^2(u)du = \int_0^{n\pi} \cos^2(u)du = \frac{n\pi}{2}$$



60. A piston is pressed with a force $\vec{\mathbf{F}}$ on a hydraulic cylinder containing water ($\rho = 10^3$ kg/m^3). The cross sectional area of the cylinder is $A = 400$ cm^2. The water therein is forced into a pipe with a cross sectional area of $a = 2$ cm^2 that rises vertically a height $H = 40$ meters. Both the end of the pipe (at the top) and the back of the piston (at the bottom) are open to atmospheric pressure.

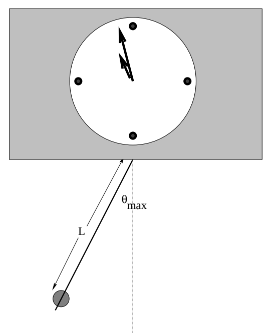
    What does F have to be to make the water spurt from the pipe with a speed of 10 meters/sec at the top?



61. A pump is a machine that can maintain a pressure differential between its two sides. A particular pump that can maintain a pressure differential of as much as 10 atmospheres of pressure between the low pressure side and the high pressure side is being used on a construction site.

    a) Your on-site construction boss has just called you into her office to either explain why they aren't getting any water out of the pump on top of the 25 meter high cliff shown above. Examine the schematic above and show (algebraically) why it cannot possibly deliver water that high. Your explanation should include an invocation of the appropriate physical law(s) and an explicit calculation of the highest distance the a pump *could* lift water in this arrangement. Why is the notion that the pump "sucks water up" misleading? What really moves the water up?

b) If you answered a), you get to keep your job. If you answer b), you might even get a raise (or at least, get full credit on this problem)! Tell your boss where this single pump should be located to move water up to the top and show (draw a picture of) how it should be hooked up.



62. A grandfather clock is constructed with a pendulum that consists of a long, light rod and a small, heavy mass that can be slid up and down the rod to "tune" the clock. It keeps perfect time when the period of oscillation of the mass is $T = 2$ seconds. When the clock is running, the maximum angle the rod makes with the vertical is $\theta_{\rm max} = 0.05$ radians (a "small angle").

a) *Derive* the equation of motion for the rod when it freely swings and solve for $\theta(t)$ assuming it starts at $\theta_{\rm max}$ at $t = 0$.

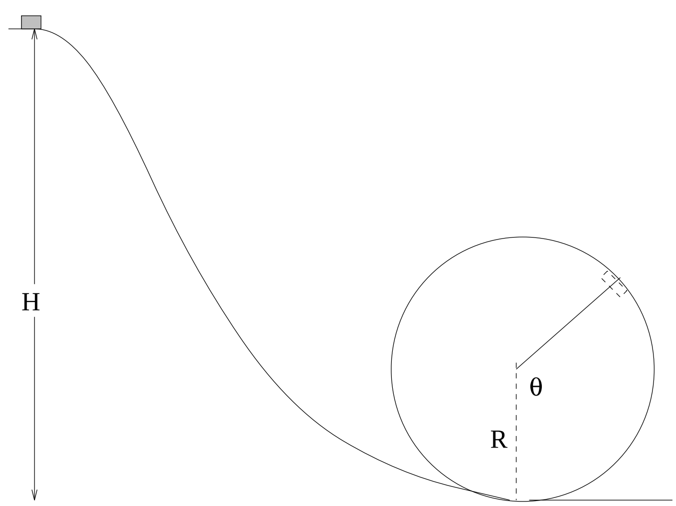
b) At what distance L from the pivot should the mass be set so that the clock keeps correct time?

63. A string of mass density μ is stretched to a tension T and fixed at $x = 0$ and $x = L$. The transverse string displacement is measured in the y direction. All answers should be given in terms of these quantities or new quantities you define in terms of these quantities.

a) Write down the wave equation (the differential equation of motion) for waves on a string. (For extra credit IF YOU HAVE TIME AT THE END you can derive it and deduce the formula for the wave velocity.)

b) Find $k_n, \omega_n, f_n, \lambda_n$ for the first four modes supported by the string. Sketch them in on the figure above, labelling nodes and antinodes.

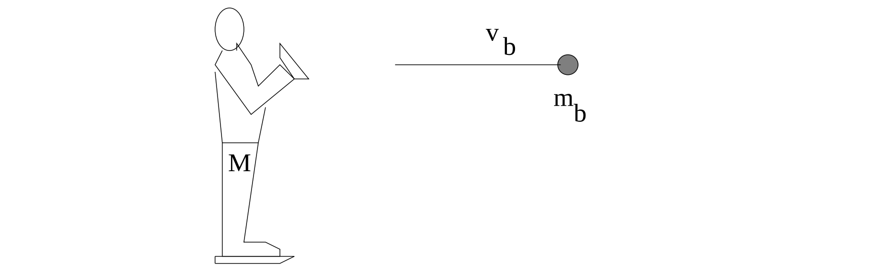
c) Write down the equation $y_n(x,t)$ for a generic standing wave on this string with mode index n, assuming that the string is maximally displaced at $t = 0$.



64. A block of mass M sits at the top of a frictionless loop-the-loop of height H. It slides down.

Find the total force (magnitude and direction) acting on the mass when the mass is at an angle θ on the loop as shown in terms of M, g, R and θ. Draw the components in on the figure above.

For extra credit, find the magnitude of the normal force only.

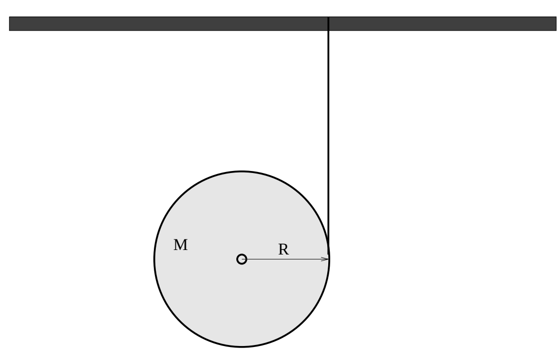


65. An ice skater of mass $M = 80$ kg (on frictionless ice) catches a softball of mass $m_b = 500$ gm incident from the right at $v_b = 30$ m/sec (in the negative x-direction relative to the ground) as shown.

a) What is the recoil velocity of the skater after catching the ball?

b) How much energy was dissipated (as heat) by the baseball glove when the skater catches the ball?

c) If the skater misses the ball and is beaned in the noggin so that the ball bounces back in the direction from which it came, does the skater recoil faster or slower than he did when catching the ball in a)?



66. A spool of fishing line is tied to a beam and released from rest in the position shown at time $t = 0$. The spool is a disk and has a mass of 50 grams and a radius of 5 cm. The

line itself has negligible mass per unit length. Once released, the disk falls as the taut line unrolls.

a) What is the tension in the line as the disk falls (unrolling the line)?

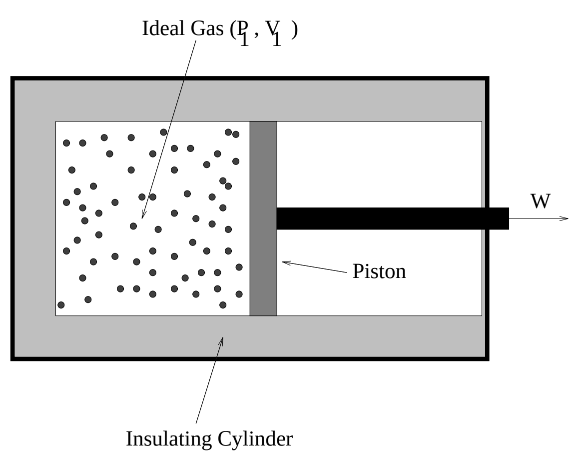
b) After the disk has fallen 2m, what is its speed?

67. Cool stuff about gravity. A neutron star has a mass $M = 10^{30}$ kg and a radius of perhaps 8 km. Draw a picture of it above.

a) What is the escape velocity from the surface of the neutron star? Express the result as a fraction of c, the speed of light $c = 3 \times 10^8$ m/sec.

b) A comet with a mass $m = 10^{14}$ kg falls from infinity into the neutron star. What is the energy liberated as it (inelastically) hits?

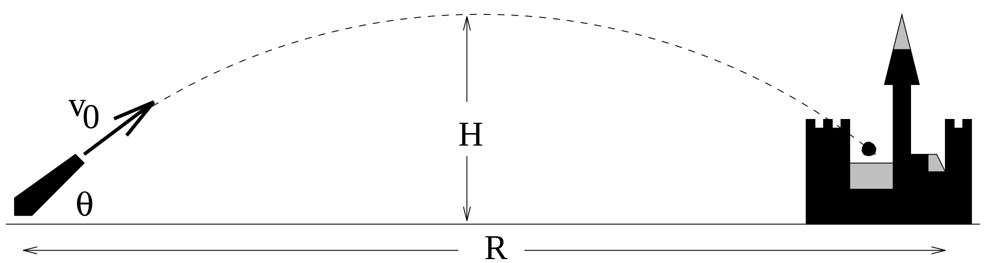
c) Compare this energy to the total mass energy of the comet, mc^2.



68. N molecules of an ideal monoatomic gas at initial volume V_1 and pressure P_1 expands in a cylinder quasi-statically and adiabatically (so that $dU + PdV = 0$) to volume V_2 and pressure P_2. All answers should be expressed in terms of these quantities, k and $\gamma = C_p/C_v$. Calculate the work done two ways:

a) Integrate $dW = -C_v dT$ (and put the answer in a form with only the variables noted above). I did this in lecture for you.

b) Integrate $dW = PdV$ directly, using the equation of state satisfied by an adiabatically expanding gas. Show that the two answers are equal (I noted the equality in class and assigned this problem for homework).

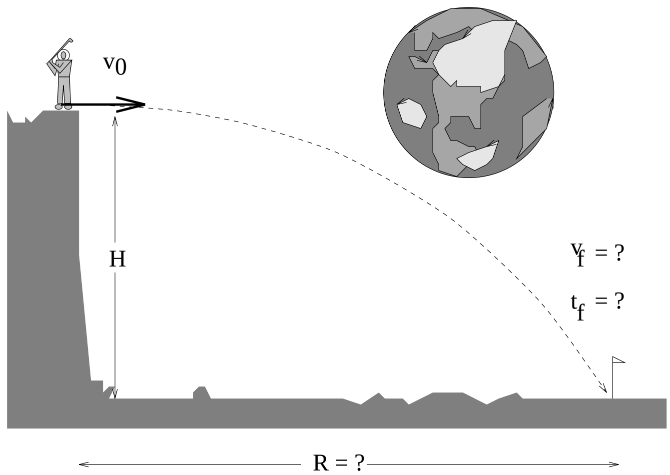


69. A cannoneer is trying to hit a city on a plain. The city is $R = 2$ kilometers horizontally away from the cannon mouth. The cannon fires projectiles only at $v_0 = 200$ m/sec. Assume $g = 10$ m/sec^2.

a) Find the angles at which the cannoneer can set the cannon in order to destroy the city.

b) How high does the cannonball go in each case?

c) How long do the people in the city have to wait between seeing the flash of the cannon and the arrival of the cannonball? Obviously we should ignore the speed of light in this one...

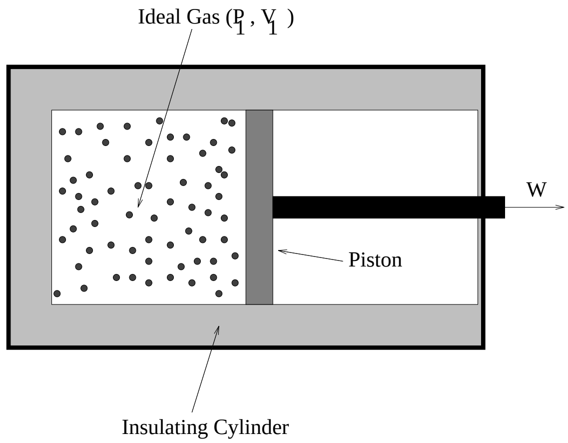


70. An astronaut on the moon hits a golf ball horizontally from the top of a cliff 750 m high. The initial speed of the ball is $v_0 = 120$ m/sec. Assume that the acceleration due to gravity on the moon is $a_m = g/6 = 5/3 = 1.67$ m/sec^2.

a) How long does it take the ball to reach the ground (neglect the curvature of the moon)?

b) How far from the base of the cliff does the ball strike?

c) How fast is the ball going when it hits the ground?



71. N molecules of an ideal monoatomic gas at initial volume V_1 and pressure P_1 expands in a cylinder quasi-statically and adiabatically (so that $dU + PdV = 0$) to volume V_2 and pressure P_2. All answers should be expressed in terms of these quantities, k and $\gamma = C_p/C_v$. Calculate the work done two ways:

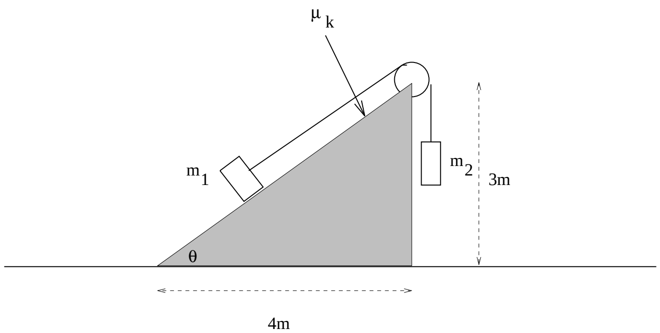
a) Integrate $dW = -C_v dT$ (and put the answer in a form with only the variables noted above). I did this in lecture for you.

b) Integrate $dW = PdV$ directly, using the equation of state satisfied by an adiabatically expanding gas. Show that the two answers are equal (I noted the equality in class and assigned this problem for homework).

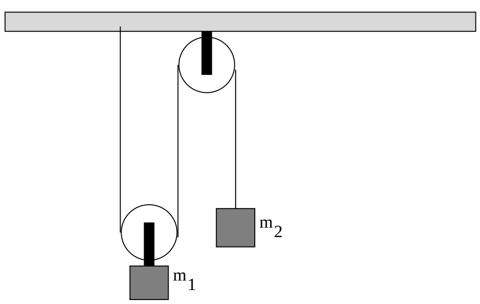
72.
- For each of the following figures, draw a "free body diagram" for **each** mass shown, that is, draw in and label all *real* forces acting on it;
- For each of the following figures, apply **Newton's Second Law** in appropriate coordinates to **each** mass shown;
- Pick **one** figure and solve for the acceleration(s) of **each** mass shown and evaluate **all** unknown forces (such as a normal force or the tension in a string) in terms of the given quantities.

Don't forget that the acceleration is a **vector** and must be given as a magnitude and a direction (for example, "along the plane to the right" is ok) or in vector components. (5 points each + 5 points for finding unknowns for one of them.)

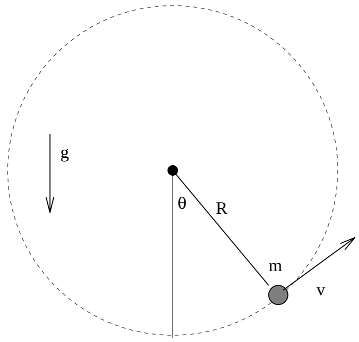
(a) $\theta = 36.87°$, $m_1 = 10$ kg, $m_2 = 20$ kg, $\mu_k = 0.1$



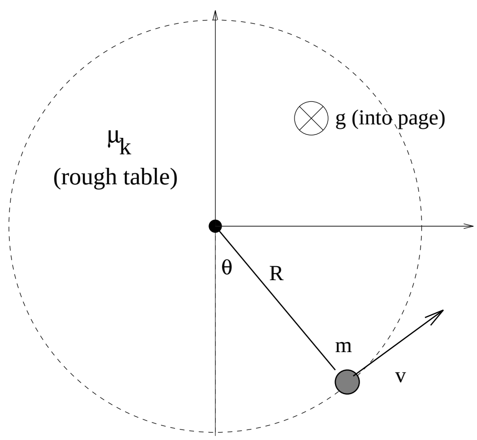
(b) $m_1 = m_2 = 8$ kg.



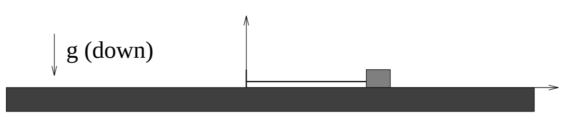
(c) $r = 2.0$ m, $\theta = 45\circ$, $m = 5$ kg, $|\vec{v}| = 10$ m/sec.



(d) This is a block whirled on the end of a string sitting on a rough table. Gravity is **into** the page. Given: R, m, v, μ_k, θ.



Top View



Side View

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