PHY180 Midterm Review Questions

Modelling Questions

1. A pendulum for the PHY180 project uses nylon string (E = 3 x 109 Pa). Estimate the extra stretching of the pendulum at the bottom of its swing versus when it's hanging at rest
2. What is the fastest safe speed for a car to go around a banked curve of a highway exit ramp?
3. An athlete does a standing long jump: they start from rest, then jump as far (horizontally) as they can. What average force (magnitude) did the ground exert on the athlete during the jump?
4. Estimate Young's modulus of a bungee cord. A bungee cord can be used to allow people to safely jump off a bridge.
5. What is the temperature increase of a person who climbs up the CN tower compared with someone at rest (assuming no heat flow)? (Really: how much do you need to sweat?)
6. How far will a kicked soccer ball go? Do not ignore air resistance.
7. You hold a feather pillow up. You let go of it while hitting it with your other hand. How much does its temperature increase?

Numberless Questions

1. A mass m hangs from a string of length L. It's set in motion swinging in a horizontal circle (a so-called conical pendulum). The string makes a constant angle with respect to the vertical. How long does it take for the mass to complete one circle?
2. A mass slides down a frictionless ramp into a loop. How high above the bottom of the loop does the mass need to be released in order to make it all the way around the loop without falling off?
3. Can you balance a box on a log?
4. Assuming an electric car (mass m) has a maximum power P that can be delivered to the wheels (and that the tires won't slip), find the speed of the car as a function of time if it starts at rest and then accelerates at full power.
5. Find the center of mass of a triangle with uniform density.
6. Find the moment of inertia of a triangle with uniform density.
7. Two identical carts of mass m are connected with a spring with spring constant k. You apply a constant force F on one cart for a short distance d, which takes a time T, then let go. You watch the system for a long time. What is the maximum compression of the spring while you watch?

<u>Question 1</u> [4 marks]

An amusement park ride consists of a metal cylinder with rubber on the walls. People stand against the wall, and the ride starts spinning faster and faster. When it gets to full speed, the floor drops away but the people stick to the wall. Write a sample blog article suitable for a general audience (people who did not do high school physics) which explains the physics of this “magic” whereby they don’t fall. You may not use any equations or physics jargon. The word force **is not** jargon, but the vector nature of forces **is** jargon. Your answer should be around 100 to 150 words.

The reason this works is friction. When two objects are squeezed together, friction always acts to try to prevent two objects from sliding. At first, the person is standing against the wall, and it’s friction between their feet and the floor that makes them speed up. Once the person is moving, they want to move in a straight line, but that would make them go through the wall. The wall prevents that by pushing them toward the middle of the cylinder. This generates the squeeze. Due to this squeeze, the wall can exert a friction force to prevent the person from slipping in any direction, including down. So when the floor lowers away, that friction force acts to balance gravity and prevent them from sliding down. This does require a sticky wall, hence the wall is made with rubber.

Note: key issues is that it’s friction which is preventing the slipping, and that this friction requires a normal force (though normal force is jargon). The normal force is a response to the spinning and the person wanting to go in a straight line. A diagram for this question would be very helpful!

Question 2 [4 marks]

We know that an electron orbiting the hydrogen atom must have quantized energy levels. Write a sample blog article suitable for a general audience (people who did not do high school physics) which explains how we know this is true. You may not use any equations or physics jargon. Your answer should be around 100 to 150 words.

The principle evidence for this is that hot hydrogen gas glows with a distinct colour, just like neon lights. In fact, every gas glows when it's warm, and they all glow with different and distinctive colours. If you aim their light through a glass prism which would convert white light into a rainbow, the light from hydrogen does not produce a rainbow. Instead, it produces just a couple of narrow bands of colour, specific parts of the rainbow. And every other gas does something similar, but with different colour combinations. Since the energy of light particles depends on their colour, and since only very specific colours come out of hydrogen, we know that the light coming out of the hydrogen gas has very specific energy values. Since this light ultimately comes from the energy of the atoms, specifically the electrons changing energy states, we know that the energy states of a hydrogen atom must be quantized.

Note: key issue here is either emission or absorption lines being narrow bits of the rainbow spectrum. Energy is not jargon, but energy levels is. If students explain what energy levels are, that's fine. But if they just talk about the Bohr model, that's a model and not really evidence for how we know that the model is correct. The basic ideal of an atom being a nucleus with orbiting electrons is not jargon, I think most people know that basic fact.

Another approach is the Franck-Hertz experiment as described in the textbook: collisions of electrons with atoms (mercury vapour) are either elastic or inelastic with an exact amount of energy lost (4.9 eV for mercury). There's nothing in between.

<u>Question 3</u> [8 marks]

<u>Numberless question:</u>

The force between two identical magnets (equal mass, size, etc) set up to repel each other is

$$F(x) = F_0\,(L/x)^4$$

where x is the distance between the two centers and F_0 is the force measured when $x = L$. If both of the bar magnets are released from rest at $x = L$, how much kinetic energy will each magnet have when they get far away from each other? Answer in terms of some or all of: F_0, L.

This force can be converted into a potential energy with calculus:

$U = - \int F(x)\,dx = - \int F_0\,(L/x)^4\,dx = - (-1/3)\,F_0\,L^4\,x^{-3} + C$

It's convenient to take $C = 0$ since that makes $U = 0$ at $x = \infty$. The energy must be positive since this is repulsive, which means you store energy by bringing them close together. We get

$U(x) = 1/3\,F_0\,L^4\,x^{-3}$

Now we have energy conservation:

$(1/3)\,F_0\,L^4 / L^3 + 0 = 0 + 2\,K$

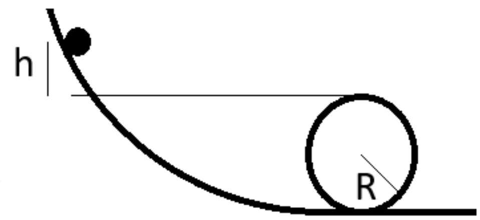
$K = 1/6\,F_0\,L$

Each object has kinetic energy of $1/6\,F_0\,L$.

Question 4 [8 marks]

Numberless question:

A ball (mass m, radius r) rolls without slipping down a hill and around a loop (radius R) as pictured on the right. From measurements, you know that $r = 0.1R$. By trial and error, it is discovered that the lowest height above the **top** of the loop which permits the ball to roll around the loop without falling out is h = 0.8R. Find the moment of inertia of the ball. Ignore air resistance and rolling friction. Answer in terms of some or all of: m, r, and g.



The lowest height corresponds to the situation that the normal force of the top of the loop on the ball (down) is zero, so only the force of gravity acts on the ball. Since the ball is going in circular motion of radius R – r and speed v we know that the net force must be

$m\, v^2 / (R - r) = m\, g$

We will also conserve energy so that we can find v^2:

$m\, g\, h = \frac{1}{2}\, m\, v^2 + \frac{1}{2}\, I\, \omega^2$

Assume the moment of inertia of the ball is $I = X\, m\, r^2$ *where X is an unknown constant. We want to find X. And replace* $\omega = v / r$.

$m\, g\, (0.8\, R) = \frac{1}{2}\, m\, v^2\, (1 + X)$

Eliminate the v^2 *terms by combining this equation with the first one (from the forces):*

$g\, (0.8\, R) = \frac{1}{2}\, g\, (R - r)\, (1 + X)$

$1 + X = 1.6\, R / (R - r)$

Finally, eliminate R by using $R = 10\, r$

$1 + X = 1.6\, (10 / 9)$

$X = 16 / 9 - 1 = 7 / 9$

So the moment of inertia is $I = (7 / 9)\, m\, r^2$

NOTE: the definition of h is a bit fuzzy here, I should have been more clear. The above interpretation is if you pick the top of the ball to be 0.8 R above the top of the loop. Other interpretations could have h be actually 0.9 R or 1.0 R. This would give X = 1 or X = 11/9. We will accept all of these answers as correct.

Question 5 [8 marks]

Modeling question:

Assume that a cheetah can chase its prey at top speed for about 30 seconds. How much will the cheetah's temperature increase during those 30 seconds?

Assume a cheetah can output constant power. Assume it initially accelerates at 10 m/s^2 so its speed is 10 m/s after 1 second. Find the average power output during that second and estimate that as the constant power.

$P = ½ m v^2 / (1 s) = 50 m$

where m is the mass of the cheetah. The total energy is thus E = P (30 s) = 1500 m

Assume an efficiency of around 33% so that the muscles generate 2 E = 3000 m joules of thermal energy. Also assume no heat flow with the environment, so the thermal energy heats the cheetah.

$3000 m = m C \Delta T$

Assume the average specific heat capacity of a cheetah is 3000 J / kg K (i.e. a little smaller than water, given that animals are mostly water). That gives us a temperature change of 1 degree celsius. Note that the mass cancels out since we assume the heat is evenly distributed over the entire cheetah.

Alternate approach: drag force of a cheetah is

$F_D = ½ C_D \rho A v^2$

Assume cheetah has an area of about 30 cm x 100 cm, density of air is about 1 kg / m^3, drag coeffecient is small (½), that's about 68 N. Assume the cheetah travels at top speed 30 m/s for 27 seconds and ignore the drag force until it hits top speed. That gives a distance of about 800 meters, and a work of about 54 kJ.

Assume a mass of about 30 kg, and otherwise similar values (efficiency, specific heat capacity), and we get about 1.2 degrees celsius.

A slightly worse method is to assume constant force instead of constant power or looking at the drag force. We otherwise use the same values (C, efficiency, etc).

Assume a cheetah has a top speed of 30 m/s and can get to that speed in about 3 seconds. That means it has an acceleration of about 10 m/s^2, about the same value as g.

If the cheetah has a mass m, it can generate a force of F = 10m. Assume that it applies this constant force for the entire race. If we know the distance traveled, we can estimate the work done.

The distance traveled is

$d = \frac{1}{2} (10\ m/s^2)(3\ s)^2 + (30\ m/s)(27\ s) = 855\ m$.

The work done is thus $W = 8550\ m$.

Assume an efficiency of around 33% so that the muscles generate $2\ W = (17\ m)$ kJ of thermal energy.

Assume no heat flow with the environment. That 17 kJ turns into heat as

$(17\ m)\ kJ = C\ m\ \Delta T$

See, the mass cancels out if we assume that the entire cheetah heats up, not just its muscles.

$\Delta T = 17\ kJ / C$

Assume $C = 3000\ J / kg\ °C$ which is a little less than water, and animals are mostly water.

This gives a temperature increase of about 5.7 degrees celsius.

Looks like the range of 0.3 degrees to maybe 3 degrees could all be plausible. Above 3 degrees and there might be a questionable assumption involved.

<u>Question 6</u> [8 marks]

<u>Modeling question:</u>

Determine the minimum quantum of vibrational energy that steel atoms can transfer between each other. You can assume that the average distance between neighbouring atoms in steel is around 0.3 nm. You may assume the results of the energy levels of a quantum harmonic oscillator are $E_N = (N + ½)\, \hbar\, \omega$; you should explain why this is useful for your model.

The minimum quantum of vibrational energy means the QHO goes from N to N+1, and therefore $\Delta E = \hbar\, \omega$.

Assume $\omega = (k/m)^2$ i.e. the individual atoms behave like masses on springs with spring constants k. We thus need to find the effective spring constant of steel and the effective mass of one steel atom. Page 2 of the test has the density and elasticity of steel.

$\rho_{steel} = 7.85 \times 10^3\ kg / m^3$
$E = 2.0 \times 10^{11}\ Pa$

Young's modulus is defined as E = stress / strain = $(F / A) / (\Delta L / L)$. If we are modeling the atoms as cubes of side $d = 0.3$ nm we get $A = d^2$ and therefore

$E = F / (d\ \Delta L)$

which we rewrite to look like the spring force law

$F = (E\ d)\ \ \Delta L$

therefore the spring constant is $k = E\ d$. We thus have a numerical value for k.

For m we use the density

$\rho = m / V \rightarrow m = \rho\ V = \rho\ d^3$

so m is now known too. Putting it together we get

$\omega^2 = k/m = (E\ d) / (\rho\ d^3) = E / (\rho\ d^2)$

$\omega = 1.7 \times 10^{13}\ s^{-1}$

Energy $= 1.8 \times 10^{-21}\ J = 0.011\ eV$

Note: students might know steel is mostly iron, and iron has a mass of around 56 protons or just under 10^{-25} kg. This gives $\omega = 2.5 \times 10^{13}\ s^{-1}$, and $2.7 \times 10^{-21}\ J = 0.017\ eV$. Probably give answers in the 0.003 eV to 0.03 eV range credit (around 0.6 to 6×10^{-21} J).