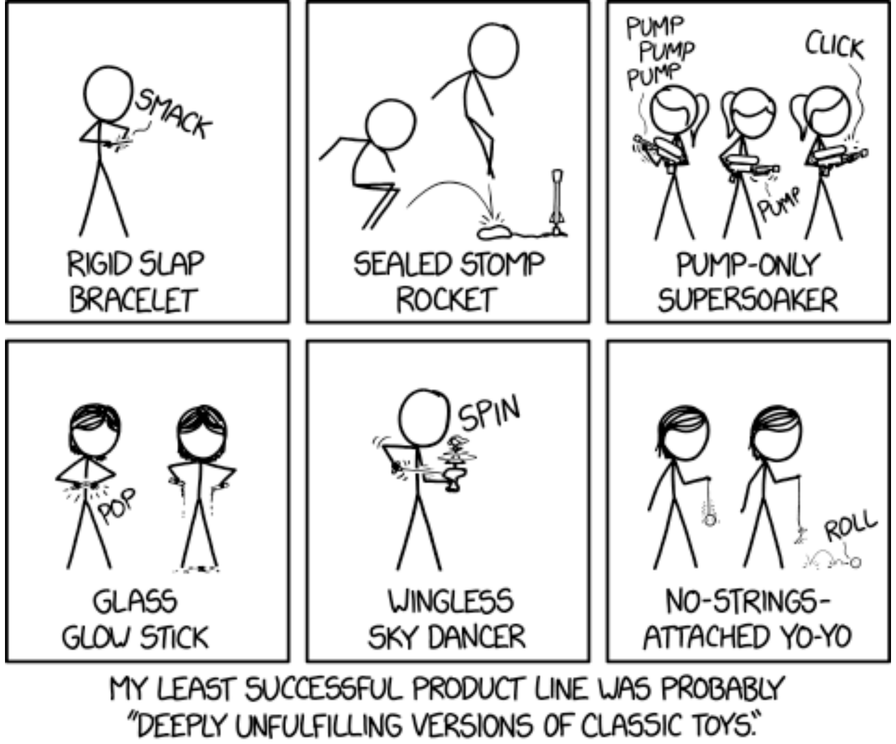
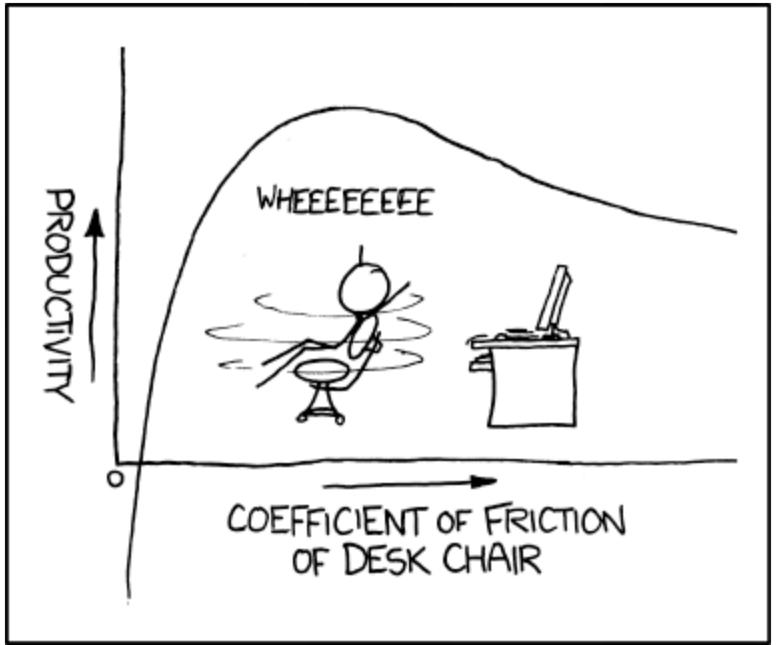
PHY151 Practical 8

Today we're doing physics with yo-yos (yo-yos are toys from before the internet when children were sad)





Outline for Today

- 6:10 - 7:00 – Practice problems
  - Do them

- 7:00 - 9:00 – Practical Activities
  - Mechanics Module 6, Activities 13, 6, 7 and 8 (Activity 9 if you have time.)

Last week's practical

1. Human error not specific enough

1. Define your variables
   - "The mass of the cart was measured witha digital scale to be *m* = (15.61 ± 0.23) kg, where uncertainty is half the least count of the digital scale."

1. Steps not in the manual must be explained in detail (e.g. how you get uncertainty from Tracker)

Explain all uncertainties. You must show how you got any uncertainties on final results.
If you have for instance $E = mgh$, you are **assuming** g = 9.81 kg m s^{-2} and you **measure**

m = (15.61 ± 0.23) kg and h = (2.654 ± 0.005) m

$E = mgh$
E = (15.61 kg)(9.81 kg m s^{-2})(2.654 m)
E = 406.4179… J

$\%m = \delta m$/m*100%
$\%m$ = (0.23 kg)/(15.61 kg)*100%
$\%m$ = 1.473…%

$\%h$ = (0.005 m)/(2.654 m)*100%
$\%h$ = 0.1883…%

$\%m$ is bigger so we'll assume $\%E \approx \%m$ so
δE = (E)($\%E$)/(100%)
δE = (406.4179… J)(1.473…%)/(100%)
δE = 5.986… J

Therefore, E = (406.4 ± 6.0) J

$E = mgh$
E = (15.61 kg ± 0.23 kg)(9.81 kg m s^{-2})(2.654 m ± 0.005 m)
E = ????

Today’s Tutorial Problems

1. The problem says “ignore rolling friction”, **this is a mistake**, without rolling friction, the disc and ring would just slide down the ramp without rolling!
2. Assume that the triangle has a constant surface density (i.e. any two equal area subsections of the triangle will have the same mass). From this, you can reason why the linear density has the suggested form.
3. More of the same
4. Again, pretty straight forward, you can probably guesstimate how big the trunk (or boot in British english) of a car is, then just use the equation you know for rotational kinetic energy.

Today’s Tutorial Problems

1. Energy conservation:

   $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}mv^2(1+X)$

   where $X = 1$ for the hoop and $X = \frac{1}{2}$ for the disk. Note that we’ve assumed rolling without slipping which means $v = \omega r$. This gives us

   $v^2 = \frac{2gh}{1+X}$

   The winner will be the one with the higher speed (both have constant accelerations, different from each other, and start from rest). the disk (smaller X) will be the winner.

   Conceptual explanation using forces/torques: both objects must rotate as well as move. Making the hoop rotate requires a larger torque. The torque comes from static friction (they roll without slipping). So the hoop has a larger static friction, which points uphill, thus slowing down its centre-of-mass-motion.

   Conceptual explanation using energy: they have the same mass and thus the same gravitational potential energy. The hoop needs to put more potential energy into rotating energy which leaves less for the linear kinetic energy. Linear kinetic energy is what wins the race.

Today’s Tutorial Problems

2. The mass of a triangle from tip to base clearly goes like x^2 (base time height) assuming a constant thickness (i.e. this is not a pyramid). If $m(x) \sim x^2$ then $\frac{dm}{dx} \sim x$ where I’m using $\sim$ to mean ‘goes like’.

   $M = \int dm = \int Ax\,dx = \frac{1}{2}AL^2 \to A = \frac{2M}{L^2}$

   $x_{CM} = \frac{1}{M}\int x\,dm = \frac{1}{M}\int xAx\,dx = \frac{2}{L^2}\frac{1}{3}L^3 = \frac{2}{3}L$

   $I_P = \int x^2\,dm = \int x^2 Ax\,dx = \frac{2M}{L^2}\frac{1}{4}L^4 = \frac{1}{2}ML^2$

   $I_{CM} = \int(x - x_{CM})\,dm = \int(x - \frac{2}{3}L)^2 Ax\,dx = \frac{2M}{L^2}\int(x^3 - \frac{4}{3}Lx^2 + \frac{4}{9}L^2x)\,dx$

   $I_{CM} = \frac{2M}{L^2}(\frac{1}{4}L^4 - \frac{4}{9}L^4 + \frac{2}{9}L^4) = \frac{1}{18}ML^2$

   $I_P = I_{CM} + M(\frac{2L}{3})^2 = ML^2(\frac{1}{18} + \frac{4}{9}) = \frac{9}{18}ML^2 = \frac{1}{2}ML^2$

Today's Tutorial Problems

3. The acceleration of the ball is constant. So we can find the acceleration from kinematics as

   $a = \frac{v^2}{2d}$

   where d is how far it travels from rest and v is the final speed. The final speed comes from energy, which was done in question 1.

   $v^2 = \frac{2gh}{1+X} = \frac{2gd\sin\theta}{1+X}$

   $a = \frac{g}{1+X}\sin\theta$

   Using the small angle approximation, we get that the slope of the graph should be $slope = \frac{g}{1+X}$.

   I get slopes between $\frac{3.9-0.1}{0.6-0} = 6.3$ and $\frac{4-0}{0.58-0.02} = 7.1$ if I ignore the 2 right-most data points (where the small angle approximat might break down). This gives values of X between 0.55 and 0.37. Call it 0.46 ± 0.09.

Today’s Tutorial Problems

4. $E = \frac{1}{2}I\omega^2 = \frac{1}{4}Mr^2\omega^2 < \frac{1}{4}M(100\,\mathrm{m/s})^2$

   A flywheel that fits in the trunk of a car probably has a heigh of about 0.5 m and a radius probably about 0.5 as well. The volume of a cylinder is $V = \pi r^2 h$ and the mass is $M = \rho V$ where ρ is the density of steel (given). That means the mass is likely to be about 3000 kg.

   That’s more than the mass of the rest of the car!

   Total energy is about 8 MJ. That’s a lot of energy. Let’s compare this with the kinetic energy of a car going at highway speeds (30 m/s). Assume this car is about 4000 kg (since the flywheel is so heavy), that gives 1.8 MJ. So this engine can get us up to high speed with room to spare, so energy storage seems fine.

   The angular momentum of the flywheel at full capacity is $L = I\omega = 75000\,\mathrm{kg\,m^2/s}$, pointed vertically. Let’s assume it points up. Going up a round hill, the torque of gravity around the back wheels (assuming the front wheels are trying to lift off the ground) is around 90000 N m, pointed horizontally and perpendicular to the velocity (i.e. to the left).

   Since $\frac{d\vec{L}}{dt} = \vec{\tau}$, and since $\vec{\tau}$ is neither tiny nor huge compared with $\vec{L}$, the resulting motion is complicated, but basically the front left wheel will try to stay on the ground while the front right wheel will try to lift off the ground. This presents some obvious problems.

Today’s Practical

- **Mechanics Module 6: Activities 13, 6-8** (9 if you have time)
- 13 and 7 are just theory problems
- In 6, for the yo-yo drop you will need to use the stopwatches to measure fall times. Note that this isn’t in the lab manual so you’ll need to write down your procedure.

- **Cite lab manual** or write out complete procedure
- Explain all uncertainties
- Propagate uncertainties correctly
- **REFLECT ON RESULTS!!!**