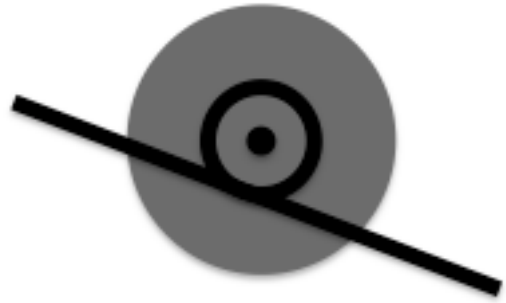
PS#10 Due Thursday Dec. 8 in class. Remember to start each question with a description of the lens and method.

1) A bicycle is a beautiful thing to me! Imagine that I can put a constant force (perpendicular to the radius of rotation) of 200 N onto the pedal that is 20 cm long, and am able to maintain that force for some time as I pedal along. Let's say that I am rotating the pedals at 60 rotations per minute. Imagine that I am riding up at constant speed against wind friction.
This discussion is posted in a video for Thursday of week 11

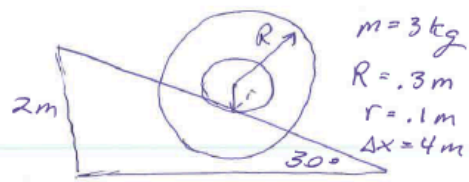
2) Remember the flywheel from the first problem in PS #7?, now it has a hub on either side, rolling down two rails inclined at 30° as shown at right. The flywheel is a 3 kg flat disk of uniform thickness and has a radius of 30 cm. The hub is of radius = 10 cm.
The flywheel starts from rest and rolls without slipping along 4 m of rail.



a) $\Delta h = 2m$

$\Delta PE = mg\Delta h = 3kg\, 10\,m/s^2\, 2m$

$= 60 \frac{kg\, m^2}{s^2} = 60 J$



$m = 3kg$
$R = .3m$
$r = .1m$
$\Delta x = 4m$

b) Energy lens –

$I = \frac{1}{2}MR^2$

$v = \omega r$

$PE \Rightarrow KE_{linear} + KE_{rotation}$

$= \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}m\omega^2 r^2 + \frac{1}{2}\frac{1}{2}mR^2\omega^2$

$mg\Delta h = \frac{1}{2}m\omega^2(r^2 + \frac{1}{2}R^2) = \frac{1}{2}m\omega^2\underbrace{(10^{-2}m^2 + \frac{1}{2}.09m^2)}_{0.55\ m^2}$

$\omega^2 = \frac{2}{0.055} 10\,m/s^2\, 2m \approx 727/s^2$

$\boxed{\omega_f \approx 27/s}$

$\omega_{ave} = \frac{\omega_f}{2} \approx 13.5/s$

$V_{ave} = \omega_{ave} \cdot r = 1.35\,m/s = \frac{\Delta x}{t}$

$t = \frac{\Delta x}{V_{ave}} = \frac{4m}{1.35\,m/s} \approx 3.0s$

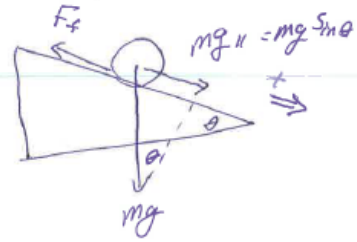
$\alpha = \frac{\Delta\omega}{\Delta t} \approx 9.1/s^2$ $\quad a = \alpha r = 0.91\,m/s^2$

$\tau = \alpha I = 9.1/s^2\, \frac{1}{2}mR^2 = \frac{9.1}{s^2}(\frac{1}{2}).3kg(.3m)^2 = 1.23\,Nm$

$F_f = ?\quad \tau = F_f r \quad F_f = \frac{\tau}{r} = 12.3N$ (up the hill)

This is now a dynamics problem

$\sum \vec{F} = m\vec{a} = mg_{\parallel} - F_f$



$= 15N - 12.3N \approx 2.7N$

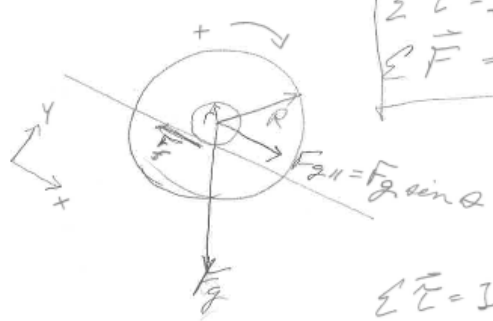
$a = \frac{\sum \vec{F}}{m} = \frac{2.7N}{3kg} \approx 0.9\,m/s^2$

which is what we calculated previously.

Below is a different way to find the answers using a dynamics approach and solving the simultaneous equations. BUT at the very end, I show you how to solve it in one line by just saying that at this instant in time, the wheel is pivoting around the point of contact and finding the torque = $F_{g(parallel)}$*r, and using the parallel axis theorem to find the moment of inertia of the wheel about this point.

$\sum \vec{\tau} = I\vec{\alpha}$ $\quad a = \alpha r$

$\sum \vec{F} = m\vec{a}$



$\sum \vec{\tau} = I\vec{\alpha}$ $\quad \sum F = ma$

$F_f r = I\alpha$ $\quad F_{g\parallel} - F_f = ma$

$F_{g\parallel} r - m\alpha r^2 = I\alpha$ $\quad F_{g\parallel} - ma = F_f$

$F_{g\parallel} - m\alpha r = F_f$

$F_{g\parallel} r = I\alpha + mr^2\alpha$

$$\boxed{\frac{F_{g\parallel} r}{\underbrace{I + mr^2}_{I_{PA}}} = \alpha}$$

$$\alpha = \frac{(mg\sin 30^\circ)(0.1m)}{\frac{1}{2}m(0.3m)^2 + m(0.1m)^2}$$ mass cancels

$$= \frac{5\,m/s^2\,(.1m)}{.0055\,m^2}$$

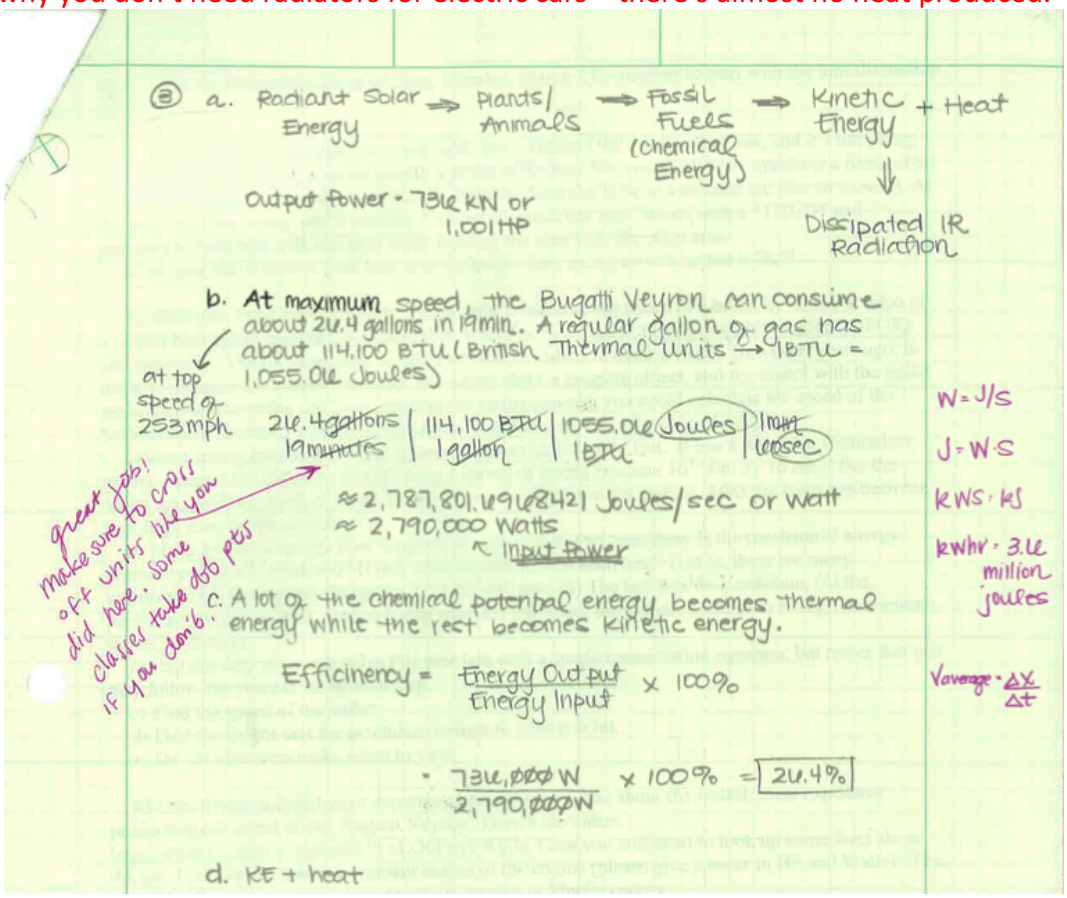
$$= 9.1/s^2$$

$a = \alpha r = 0.91\,m/s^2$

$\tau_{\text{Pt of contact}} = I_{\text{Parallel axis}}\,\alpha$

$F_{g\parallel} \cdot r = I_{PA}\,\alpha$ $\quad \alpha = \frac{F_{g\parallel} \cdot r}{I_{PA}}$

2) Cars. Folks in the physics department are making a fuss about the fastest, most expensive production car in the world, Bugatti Veyron. Here's the video: http://www.youtube.com/watch?v=LO0PgyPWE3o Then you will need to look up some facts about the car. Wikipedia has everything you need for this. Look up the maximum power output of the engine (please give answer in HP and Watts). This would be the output power of the engine in motive or kinetic energy. We can see below that the student did a great job with a-c recognizing that the car consumes energy at a rate of about 2.8 MW as it is putting out its maximum power of about ¾ MW, corresponding to about 25% efficiency, which is actually pretty good for an internal combustion engine… electric motors can be around 95% efficient, which is why you don't need radiators for electric cars – there's almost no heat produced.



(2) a. Radiant Solar Energy → Plants/Animals → Fossil Fuels (chemical Energy) → Kinetic Energy + Heat

Output Power = 736 kW or 1,001 HP

Dissipated IR Radiation

b. At maximum speed, the Bugatti Veyron can consume about 24.4 gallons in 19 min. A regular gallon of gas has about 114,100 BTU (British Thermal units → 1 BTU = 1,055.06 Joules)

at top speed of 253 mph

$\frac{24.4 \text{ gallons}}{19 \text{ minutes}} \cdot \frac{114{,}100 \text{ BTU}}{1 \text{ gallon}} \cdot \frac{1055.06 \text{ Joules}}{1 \text{ BTU}} \cdot \frac{1 \text{ min}}{60 \text{ sec}}$

≈ 2,787,801.6968421 Joules/sec or watt

≈ 2,790,000 watts

↖ Input Power

great job! make sure to cross off units like you did here. Some classes take off pts if you don't.

c. A lot of the chemical potential energy becomes thermal energy while the rest becomes kinetic energy.

$\text{Efficiency} = \frac{\text{Energy Output}}{\text{Energy Input}} \times 100\%$

$= \frac{736{,}000 \text{ W}}{2{,}790{,}000 \text{ W}} \times 100\% = \boxed{24.4\%}$

d. KE + heat

W = J/s

J = W·s

kWs = kJ

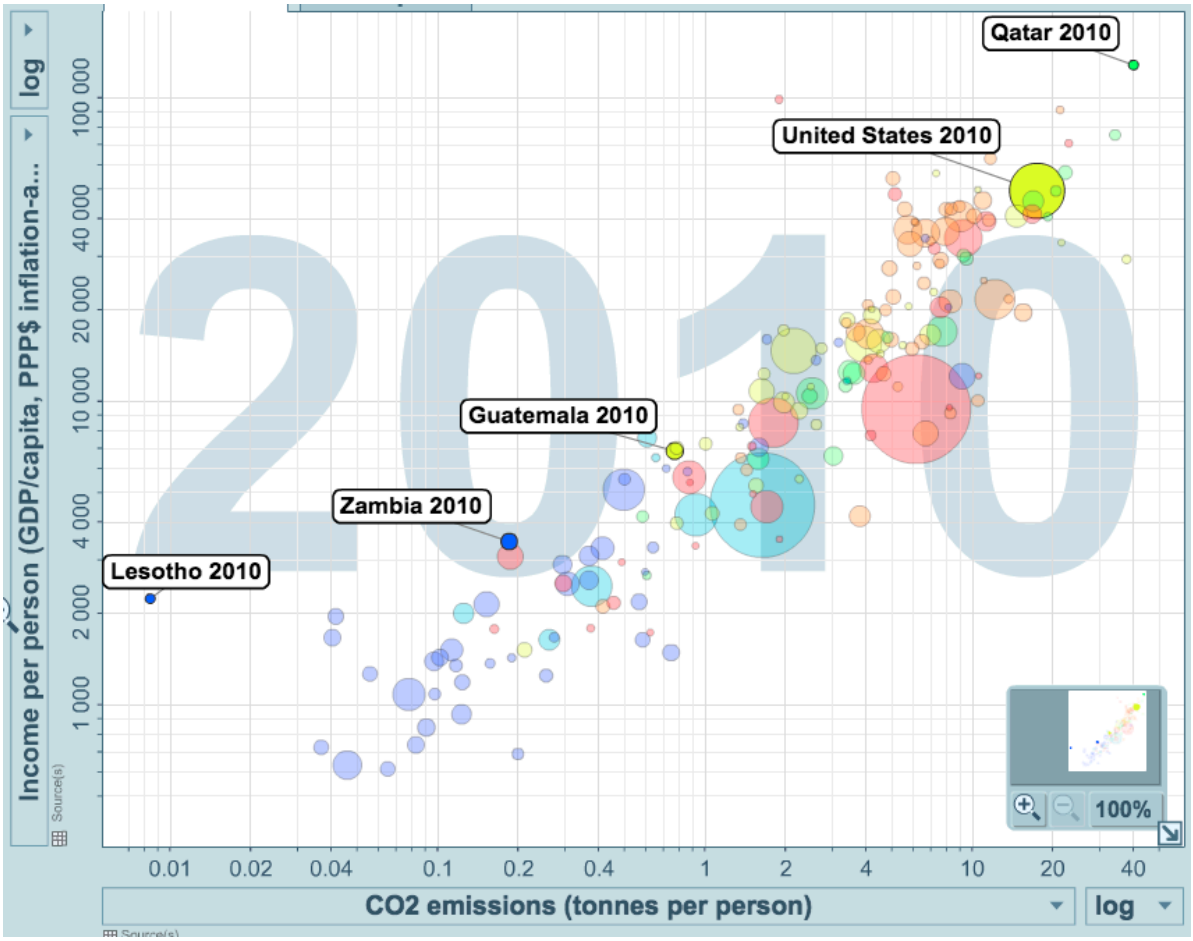
kWhr = 3.6 million joules

$V_{average} = \frac{\Delta x}{\Delta t}$

d) At what rate (in Watts) does the engine dissipate heat? Conserving energy, we take the difference in input (fuel) power and output (mechanical) power and get about 2 MW, or enough to power 20,000 100W lightbulbs (if heat energy were actually electrical energy, which it isn't), So you can see why there is the need for so many radiators – so the vehicle doesn't overheat.

e) Burning a gallon of gas releases close to 10 kg of CO_2. At what rate does the Veyron produce CO_2, a scientifically recognized climate change gas? We see from the Veyron consumes about 75 Gallons of gas per hour, emitting about 750 kg of CO_2 per hour, ¾ Ton. This is more than three times the annual emissions of the average Zambian.

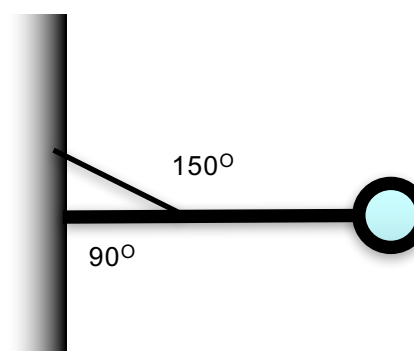
f) The Veyron costs ~$1.5 million. If you could save half your income, how long would it take you to buy one? How about the average USA citizen? The average Guatemalan? The average Zambian? We can produce lovely demographics images using Gapminder.org (below) as shown below comparing incomes and CO_2 emissions of different countries. We see that the average *per capita* CO_2 emissions and per capita annual incomes are for Lesotho (8 kg!, $2000), Zambia (200 kg, $3000), Guatemala (800 kg, $7,000), USA (18,000 kg, $46,000), and Qatar, (40,000 kg, $130,000). Hence, the amount of time needed to save $1.5 million in these countries is about Lesotho (1,500 yrs), Zambia (1000 yrs), Guatemala (500 yrs), USA (65 yrs), and Qatar, (23 yrs).



g) As you go onward to become engineers and policy makers and citizens, there will be many challenges involved with:

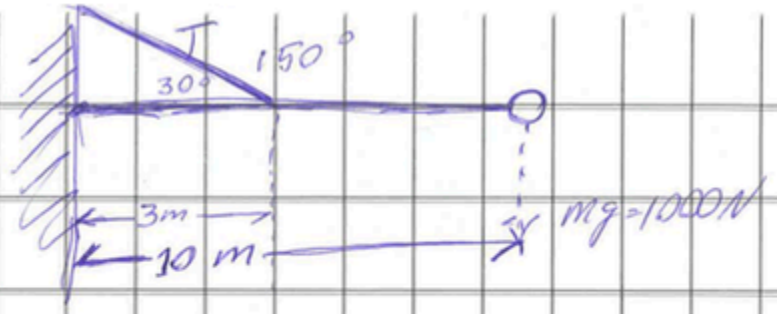
   a) how to create something like the Veyron and,
   b) If something like the Veyron should be created.

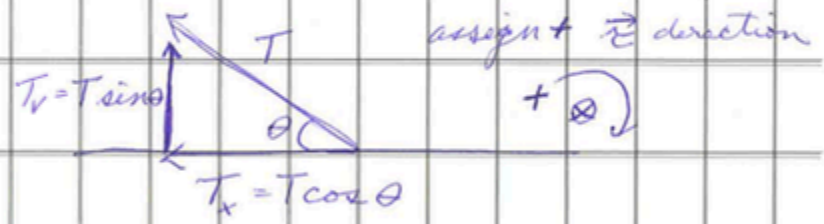
   Please consider which question is more important, or give your thoughts…. You might also inquire as to whether this last question is relevant to our course or a complete waste of time and distraction from physics. This is of course your perspective. I suppose my perspective is evident because I've included this question. If these last three questions are of interest to you, it is the subject of my group's ongoing research that you can read about at http://appropriatetechnology.wikispaces.com/PV+Research+Summer+2016 and come kick down my door if you want to know more. Also, I'm teaching PSC-320, *Energy, Society, and the Environment,* an Area F requirement, next quarter at noon MWF. Consider it.



4) Now that we've introduced Trigonometry, please solve this problem with the 100 kg sphere explicitly using the correct angles and trigonometry. The length of the pole is 10 m and the string is connected 3 m from the pivot point. Please the tension in the string and the reactive force at the pivot. Again, I start with a recognition that the acceleration and angular acceleration are zero, and we're dealing with forces, so this is a statics problem and my equations of motion are $\sum \vec{\tau} = 0, \sum \vec{F} = 0$. I start with torques and use the pivot point as the center of rotation so all the torques associated with the unknown reactive forces drop out of the equation, and I can solve for the only other unknown, Tension (or T_y as is the case). See work below.

4)





$$\Sigma\tau = 0 \qquad \tau_{string} + \tau_{gravity} = 0$$

$$\ominus\, T_y r_s + F_g r_{post} = 0$$

$$-T\sin\overset{(30°)}{\theta}\, 3m + mg\, 10m = 0$$

$$-T\left(\tfrac{1}{2}\cdot 3m\right) + 10{,}000\,Nm = 0$$

$$T \approx 6{,}700\,N$$

$$T_x = T\cos\overset{30°}{\theta} \approx 5800\,N$$

$$T_y \approx T\sin 30° = T/2 \approx 3{,}350\,N$$

To find reactive forces at pivot, we recognize that $\Sigma F_x = 0$, $\Sigma F_y = 0$ assign + directions

$\Sigma F_x = 0$, $-T_x + F_{Rx} = 0$ $\quad \Sigma F_y = 0$, $-F_g + T_y + F_{Ry} = 0$

$F_{Rx} = +5800N \Rightarrow$

$-1000N + 3350N + F_{Ry} = 0$

$F_{Ry} \approx -2350N \Downarrow$

5) The classic "notorious ladder problem": why does a ladder not slip when you stand on it at the bottom, but then it slips as you go higher? *Please don't attempt this problem until you thoroughly understand the diving board problem from previous problem sets.* Please see dedicated video.