Final Exam Review Session

Friday, March 15, 2019 7:02 PM

Physics 202

Final Exam Review Session

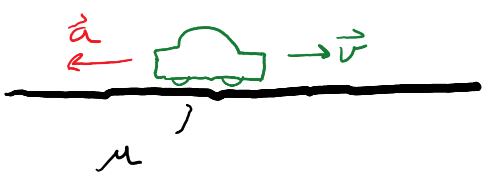
3/15/2019

The following questions are all linked together into an exploration of a common system you will use often in your life. Bringing your car to a stop involves a surprising amount of the physics you learned during PH202!

$80\left(\frac{1000}{3600}\right) = 22.2\ m/s$

1. A forumla 1 race car is travelling a velocity $v = 80\ \frac{km}{hr}$. The driver pushes the brakes and the car stops in a distance of $d = 12\ m$.

(a) What is the minimum coefficient of static friction between the tires and the road that would allow this?



$F_{frict} = \mu_s Mg$ ← can solve w/kinematics

$W = \Delta E$

$\Rightarrow \frac{1}{2}mv^2 = F_{frict}\, d \Rightarrow \frac{1}{2}\cancel{m}v^2 = \mu \cancel{m} g d$

$\mu = \frac{v^2}{2gd} = 2.1$

(b) For any given problem involving friction, what might you expect as reasonable values for a coefficient of friction? Does this answer depend on what type of friction? If so, list ranges for each different type of friction. Is the answer for part (a) reasonable? If you look up the stopping distance for your car, you will find it is more like 25 meters. What might account for the difference?

for your car $\mu \sim 1$

(rubber on cement is ~ 1)

(F1 cars have down force $\Rightarrow$ push down more than they weigh!!)

$0 < \mu_r < \sim 0.3$

$0 < \mu_k < \sim 0.6$

$0 < \mu_s < \sim 1$

} very rough!

(c) Assuming a constant acceleration, what is the acceleration necessary for part (a)?

$F = ma \Rightarrow \mu mg = ma \Rightarrow a = \mu g \sim 2g!!$

2. Let us now take the center of one wheel from the formula 1 car of the previous problem as the origin. F1 tires have a diameter, D, of 670 mm. The outside of the wheel must be accelerating ~~[illegible]~~ tangentially at a rate of $a =$ (the answer from #1c). $\nwarrow a_t$

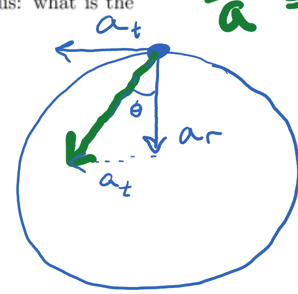
(a) What is the angular acceleration of the wheel, α?

$$\alpha = \frac{a_t}{r} = \frac{2g}{r} = 61 \frac{rad}{sec^2}$$

(b) At the instant after the driver steps on the brakes ($t = 0$), what are the tangential and radial accelerations of a pebble stuck on the outside of the tire? (Bonus: what is the angle between the acceleration vector and the radial direction?)

$$\vec{a} = \vec{a}_t + \vec{a}_r$$

$= \text{linear accel}$



$$a_t = 2g$$

$$a_r = \frac{v^2}{r} = \frac{(22.2)^2}{0.335} = 1474 \ m/s^2$$

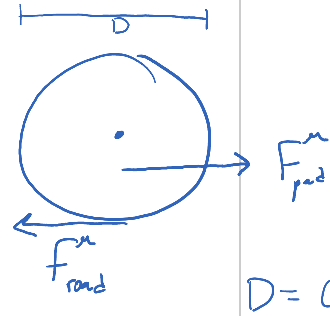
$$\tan\theta = \frac{a_t}{a_r} \Rightarrow \theta = 0.76°$$

3. To stop the car, two brake pads (yellow thing) squeeze on either side of the rotor (round shiny metal thing). The kinetic friction between them exerts a force on the wheel which slows the rotation. The mass of a formula 1 car is about 702 kg.

(a) If the force is exerted by the brake pads at $D/4$ from the center of the wheel, the coefficient of friction between each pad and rotor is $\mu = 0.6$, the mass of the wheel + rotor is 20 kg, and we model them as a solid disc, what is the normal force exerted by one pad on the rotor? hint: don't forget the force from the road! hint 2: how many pads are there? how many wheels?

m_{car}, μ_k, m_w

$I_{disk} = \frac{1}{2} m r^2$



$$\sum \tau = I\alpha$$

$$\tau_{road} + \tau_{pad} = I\alpha$$

$$-\mu_s m_{car} g\left(\frac{D}{2}\right) + \mu_k 2F^N\left(\frac{D}{4}\right) = \frac{1}{2} m_w \left(\frac{D}{2}\right)^2 \alpha$$

$D = 0.67\ m$

$\alpha = 61\ \frac{rad}{sec}$

$$F^N = \left(\frac{2}{\mu_k D}\right)\left[\frac{1}{2} m_w \frac{D^2}{4}\alpha + \mu_s m_{car} g \frac{D}{2}\right] = \boxed{24{,}400\ N}$$

(b) What is the total angle traveled by the wheel during the stopping process?

$$\Delta\theta = \frac{dist}{radius} = \frac{12\ m}{0.335} = \boxed{35.8\ rad}$$

$$\#revolutions = \frac{dist}{2\pi r} \qquad \Delta\theta = \#rev \times 2\pi = \frac{dist}{r}$$

(c) What is the work done on the rotor by the pads?

$$Work = \tau\Delta\theta = \left(2F^N \mu_k \frac{D}{4}\right)(\Delta\theta) = \boxed{176{,}000\ J}$$

4. Formula 1 rotors are usually made from carbon with a specific heat of 710 $\frac{J}{kg \cdot K}$. The mass of one rotor is about 1.2 kg.

(a) If all the work done by the pads on the rotor goes into heating the rotor, by how much does the temperature of the rotor change?

$\Delta E = cm\Delta T$

$\Delta E = W + Q$

$\Delta E = W = 176{,}000 = (710)(1.2)\,\Delta T$

$\Delta T = 207\,K$

(b) If the melting point of carbon is 3550 $°C$ and the latent heat of fusion for carbon is 355.8 $\frac{kJ}{mol}$, how much energy would it take to completely melt the rotors if they start at 80 $°C$? (bonus: how fast would the car need to be going at the start to melt the rotors by the time the car stopped?)

$\underbrace{80°C + 273°C}_{K} \longrightarrow \underbrace{3550°C + 273°C}_{K}$

$\Delta E = \underbrace{cm\Delta T}_{\Delta E_1} + \underbrace{L_f\, m}_{\Delta E_2}$

$\Rightarrow \Delta T = 3550 - 80 = 3470\,K$

$\Delta E_1 = cm\Delta T = 2{,}956{,}000\,J$

$\Delta E_2 = \left(355{,}800 \frac{J}{mol}\right)(100\,mol)$

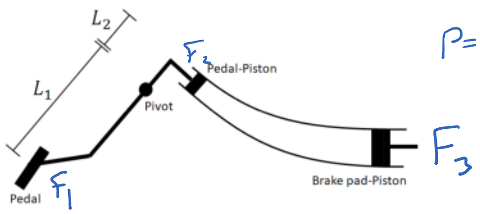
$\Delta E = 38{,}500{,}000\,J$

Carbon $\Rightarrow$ 1 mol = 12 g

$\Rightarrow 1.2\,kg = 1200\,g \Rightarrow 100\,mol$

5. To make it easier to stop the car, there is a hydraulic system that enables you to exert a large force on the rotors by pushing a small force onto the brake pedal.

(a) Let's say the radius of the piston on the brake-pad end is 2.0 cm and the radius on the pedal end is 1.0 cm. The brake pedal is as pictured, with $L_1 = 30.0\ cm$ and $L_2 = 10.0\ cm$. First, assume the pedal and brake pistons are at the same height. What force did the F1 driver exert with her foot onto the pedal?



$P = F/A$

$F_2 L_2 = F_1 L_1$

$F_1 = \left(\frac{L_2}{L_1}\right) F_2$

$F_1 = \left(\frac{L_2}{L_1}\right)\left(\frac{r_2^2}{r_1^2}\right) F_3$

$F_1 = \left(\frac{10}{30}\right)\left(\frac{1}{4}\right) F_3$

$F_1 \quad \frac{1}{12} F_3 = 2{,}000\ N$

$\sim 440\ lbs$

$F_3 \frac{A_2}{A_3} = F_2$

$F_3 \frac{\pi r_2^2}{\pi r_3^2} = F_2 \Rightarrow F_3 \frac{1^2}{2^2} = F_2$

$\Rightarrow F_3\left(\frac{1}{4}\right) = F_2$

(b) If the density of brake fluid is 1,872 $\frac{kg}{m^3}$ and the pedal-piston is 150.0 meters above the brake pad-piston: what is the pressure in the brake fluid next to the brake pad-piston? Next to the pedal-piston?

not physical

$\Rightarrow$ your brake system is better than 1:12 !!

$P_3 = \frac{F}{A} = \frac{24{,}400\ N}{\pi(.02)^2} = 19{,}400{,}000\ Pa$

$= 192\ atm!$

$P_2 + \rho g y_2 = P_1 + \rho g y_1$ ($y_2 = 0$)

$P_1 = P_2 - \rho g y_1 = 19{,}400{,}000 - (1872)(9.8)(150)$

$\boxed{P_1 = 16{,}650{,}000\ Pa}$

So far we are missing a few topics. Can you come up with a related question that involves buoyancy? PV cycles? Ideal gas law? Doppler effect? Travelling waves? SHOs? Damped SHOs? Standing wave resonance? What else have we covered this term that was not highlighted in the above problems?

Bonus online content!

This will be a new situation that will fill in a few gaps left by the previous content. (Though not all the gaps!!!)

6. A metal 10 gallon barrel is floating upright in a lake. It has a height, $\mathbf{H}$, a base of area, $\mathbf{A}$, a mass, $\mathbf{m_b}$, and has a mass, $\mathbf{m_2}$, resting inside on the bottom.

(a) Find an expression for the depth of the bottom of the barrel, $\mathbf{d_0}$.

(b) How much force, $\mathbf{F}$, does it take to push the barrel down an additional distance, $\mathbf{d}$?

(c) If we remove our hand, what is the angular frequency, ω of the barrel's oscillation? (Assume SHO motion)

(d) Assuming an amplitude, $\mathbf{A}$, find $\mathbf{f}$, $\mathbf{T}$, $\mathbf{v_{max}}$, and $\mathbf{a_{max}}$.

(e) If after 10 oscillations, the amplitude of the barrel's oscillation is $\frac{\mathbf{A}}{8}$, what is the time constant, τ?

(f) If you hit the barrel on the top of the lid, it will excite many resonant frequencies of the air inside the barrel. If the barrel has a diameter of 35.56 cm, and a gallon is 3.79 liters, what are the lowest three resonant frequencies that would be excited?