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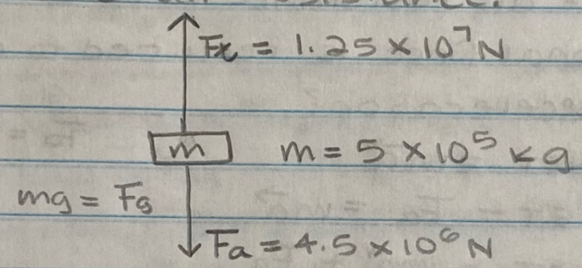
MIDTERM #2

2 Chapter 4: Dynamics, Force, and Newton's Laws of MOTION

① A 5×10^5 kg rocket is accelerating straight up. The thrusters produce an upward force of 1.25×10^7 N, and the force of air resistance is 4.5×10^6 N downward.

(a) Draw a free body diagram including the weight of the rocket, the thrust, and air resistance.



F_t = thrust force

F_a = air resistance force

F_g = force of gravity towards earth

(b) What is the rocket's acceleration?

$$\vec{F_{NET}} = m\vec{a}$$

$$\vec{F_{NET}} = F_t - F_a - F_g = ma$$

$$\vec{F_{NET}} = \frac{F_t - F_a - mg}{m} = \frac{ma}{m}$$

$$a = \frac{F_t - F_a - mg}{m}$$

$$= \frac{(1.25 \times 10^7 N) - (4.5 \times 10^6 N) - ((5 \times 10^5 kg)(9.8 m/s^2))}{5 \times 10^5 kg}$$

$$\approx \boxed{6.2 \, m/s^2}$$

② A football player with mass 70kg pushes a player with mass 90kg.

(a) According to Newton's third law, if the first player exerts a force of 700 N on the second player, what is the force the second player exerts on the first player?

$\vec{F}_{BA} = -\vec{F}_{AB}$ $\qquad$ $m_1 = 70\,kg$

$m_2 = 90\,kg$

$= \boxed{-700N}$ $\qquad$ $F_1 = 700N$

③ A rocket sled is decelerated at a rate of 200 m/s², and it has a mass of 2000 kg. There is a constant air resistance force of 1000N. What additional force is required to give the rocket the deceleration?

F_a = air resistance

$\vec{F}_{NET} = m\vec{a}$

$F_{NET} - F_a = m\vec{a}$

$F_{NET} = m\vec{a} + F_a$

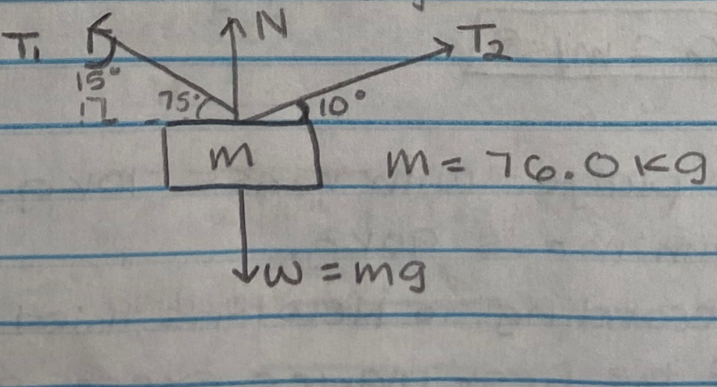
$F_{NET} = (2000\,kg)(200\,m/s^2) + (1000N)$

$F_{NET} = 401000\,N$

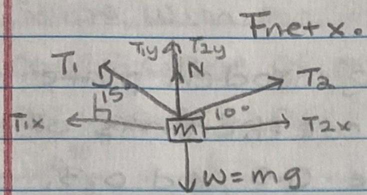
$= \boxed{401000N \text{ or } 40.1 \times 10^4 N}$

④ A 76.0-kg person is being pulled away from a burning building as shown in Fig. 1.

(a) Draw a freebody diagram including the two tension vectors and the woman's weight.



(b) write down an expression for $F_{net\,x}$.



$$\vec{F}_{NET} = m\vec{a}$$

Forces of x

$= T_1 \cos 75°$

$= T_2 \cos 10°$

$$\boxed{\begin{aligned} F_{NET\,x} &= T_{1x} - T_{2x} = 0 \\ T_{1x} &= T_{2x} \\ T_1 \cos 75° &= T_2 \cos 10° \end{aligned}}$$

(c) Write down an expression for $F_{net\,y}$.

$$\boxed{\begin{aligned} F_{NET\,y} &= T_{1y} + T_{2y} - w = 0 \\ T_{1y} + T_{2y} &= w \\ T_1 \sin 15° + T_2 \sin 80° &= w \\ T_1 \sin 15° + T_2 \sin 80° &= mg \end{aligned}}$$

(d) Assumming $\vec{F}_{NET} = 0$, calculate the tension in the two ropes.

$T_1 \cos 75° = T_2 \cos 10°$

$T_2 = 0.2628\, T_1$

0.517627477

$T_1 \sin 15° + T_2 \sin 80° = mg$

$T_1 (0.25882) + (0.2628\, T_1)(0.9848) = (76.0\,kg)(9.8\,m/s^2)$

$(0.25882) T_1 + (0.25881) T_1 = 744.8$

$0.517629\, T_1 = 744.8$

$T_1 = 1438.9\,N$

$T_2 = 0.2628(1438.9)$

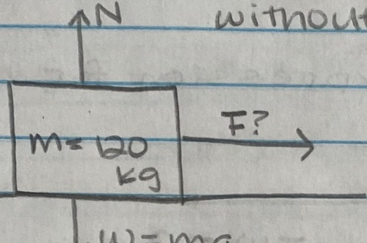
$T_2 = 378.1\,N$

$$\boxed{\begin{aligned} T_1 &= 1438.9\,N \\ T_2 &= 378.1\,N \end{aligned}}$$

3 Chapter 5: Friction, drag, and Elasticity

① Suppose you have a 120kg wooden plate resting on a wood floor. The coefficients of static and kinetic friction are 0.5 and 0.3, respectively.

(a) what maximum force can you exert horizontally on the crate without moving it?



Static friction is greater than kinetic friction.

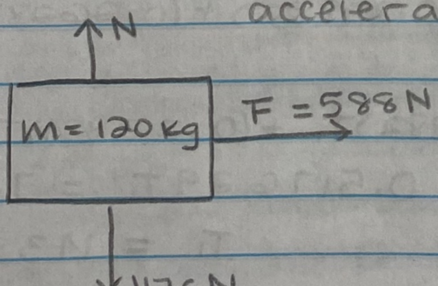
$w = mg$
$= (120\,kg)(9.8\,m/s^2)$
$= 1176\,N$

$\mu_s = 0.5 \rightarrow$ static

$\mu_k = 0.3 \rightarrow$ kinetic

$f = \mu N$
$= (0.5)(1176\,N)$
$= \boxed{588\,N}$

(b) If you continue to exert this force once the crate starts to slip, what will the magnitude of the acceleration then be?



*Kinetic friction

$\mu_k = 0.3$

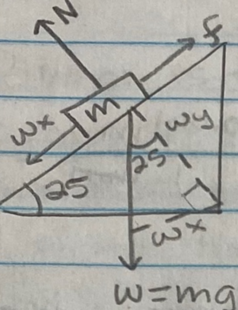
$f = \mu N$
$= (0.3)(1176\,N)$
$= 352.8\,N$

$\sum F_x = ma$

$\dfrac{588\,N - 352.8\,N}{120\,kg} = \dfrac{(120\,kg)a}{120}$

$\boxed{a = 1.96\,m/s^2}$

② Suppose a skier (Fig. 2) is sliding down a slope with an incline of 25 degrees. If the coefficient of kinetic friction is 0.1, what is the skier's acceleration?



$\mu_K = 0.1$

$\sin 25° = \frac{w_x}{w}$

$w_x = w \sin 25°$

$\cos 25° = \frac{-w_y}{w}$

$w_y = -w \cos 25°$

$f = \mu N$

$= (0.1)(w_y)$

$= (0.1)(w \cos 25°)$

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

$w_x - f = m\vec{a}$

$w \sin 25° - (0.1(w \cos 25°)) = m\vec{a}$

$w[\sin 25 - 0.1 \cos 25°) = m\vec{a}$

$\frac{\cancel{m}g[\sin 25° - 0.1 \cos 25°]}{\cancel{m}} = \frac{\cancel{m}\vec{a}}{\cancel{m}}$

$9.8[\sin 25° - 0.1 \cos 25°] = \vec{a}$

$\boxed{a = 3.25 m/s^2}$

③ DRAG FORCE Suppose the skier reaches a top speed of 40m/s. If his area is $0.75 m^2$, the density of air is $1.225 kg/m^3$, and $C = 0.75$, what is the magnitude of the drag force in Newtons?

$F_D = \frac{1}{2} C \rho A V^2$

$= \frac{1}{2}(0.75)(1.225 kg/m^3)(0.75 m^2)(40 m/s)^2$

$\boxed{F_D = 551.25 N}$

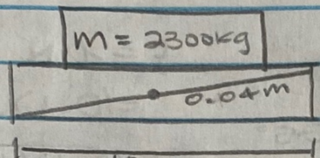
$\frac{kg}{m^3} \cdot \frac{m^2}{1} \cdot \frac{m^2}{s^2}$

$\frac{kg}{\cancel{m}} \cdot \frac{m^2}{s}$

$= kg\ m/s^2$

*④ A mass of 2300kg is placed on top of a 10.0m long wooden beam with radius 4cm. If the length of the beam decreases by 3mm, what is the Young's modulus of wood? Pay attention to the units.

$$\frac{F}{A} = Y\left(\frac{\Delta x}{L}\right)$$



$$3\cancel{mm} \cdot \frac{0.001\,m}{1\,\cancel{mm}} = 0.003m$$

$$\begin{array}{r} 10.000m \\ -\ 0.003m \\ \hline 9.997m \end{array}$$

$$4\cancel{cm} \cdot \frac{0.01m}{1\,\cancel{cm}} = 0.04m$$

Young's modulus of wood (hardwood) $= 1.5 \times 10^{10}$ Pa

$$A = r^2\pi$$
$$= (0.04m)^2\pi$$
$$= 0.0016m^2\pi$$

$$0.0016\cancel{m^2} \cdot \left(\frac{1\,mm}{0.001\cancel{m}}\right)^2 = 1600mm^2$$

$$\frac{(2300kg)}{(0.0016m^2\pi)} = Y\left(\frac{9.997\cancel{m}}{10.0\cancel{m}}\right)$$

$$\boxed{Y = 1.4\,N/mm^2}$$

4 Chapter 6: Uniform Circular Motion and Gravitation

① A pitcher in baseball pitches a ball at 144 km/hr, and the ball rotates around his arm at a radius of 0.5 meters. What is the angular velocity of the ball as he throws it, in radians per second?

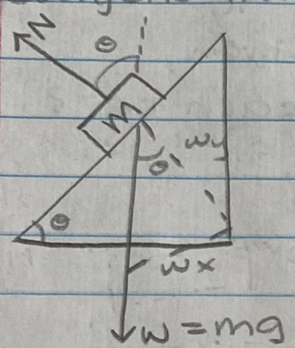
$$V = r\omega$$

$$\frac{144\,\cancel{km}}{\cancel{hr}} \cdot \frac{1\,\cancel{hr}}{60\,\cancel{min}} \cdot \frac{1\,\cancel{min}}{60\,s} \cdot \frac{1000\,m}{1\,\cancel{km}} = 144000\,m/s$$

$$\frac{144000\,m/s}{0.5m} = \frac{(0.5m)\omega}{0.5m}$$

$$\boxed{\omega = 288000 \text{ rad/s} \quad \text{or} \quad 28.8 \times 10^4 \text{ rad/s}}$$

② What is the ideal banking angle for a gentle turn of 0.9 km radius on a highway with a 120 km per hour speed limit, assuming everyone travels at the limit?



$$\frac{mv^2}{r} = N\sin\theta$$

$$mg = N\cos\theta$$

÷ → $\frac{mv^2}{r(mg)} = \tan\theta$

$$\frac{v^2}{rg} = \tan\theta$$

$$\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$$

$$= \tan^{-1}\left(\frac{(121000\ m/s)^2}{(900m)(9.8\ m/s^2)}\right)$$

$$\frac{121\,\cancel{km}}{\cancel{hr}} \cdot \frac{1\,\cancel{hr}}{60\,\cancel{min}} \cdot \frac{1\,\cancel{min}}{60\,sec} \cdot \frac{1000\,m}{1\,\cancel{km}} = 121000$$

$$0.9\,\cancel{km} \cdot \frac{1000\,m}{1\,\cancel{km}} = 900m$$

$$\boxed{\theta \approx 90^\circ}$$

③ Two race car drivers routinely navigate a turn as shown in Fig. 3.

(a) Which path may be taken at a higher speed, if both paths correspond to the same force of friction and centripetal force?

If both the force of friction and centripetal force were the same, Path 2 may be taken at a higher speed. The turn would not be as extreme, as the turn angle is minimized by cutting the corner. By increasing the radius or curvature of the car, the amount of force the tires exert on the road is reduced, increasing velocity in the equation for centripetal force: $F_c = \frac{mv^2}{r}$. Path 1 cannot have an increased speed because of the small turning angle which requires larger centripetal force.

(b) Suppose path 1 has a radius of curvature of 400m, and path 2 has a radius of curvature 800m. The coefficient of friction is 1.0. If the force of friction balances the centripetal force, what are the tangential velocities of each car?

centripetal force $= \frac{mv^2}{r}$

$$r \cdot \mu mg = \frac{mv^2}{\cancel{r}} \cdot \cancel{r}$$

$$\frac{r\mu \cancel{m} g}{\cancel{m}} = \frac{\cancel{m}v^2}{\cancel{m}}$$

$$\sqrt{r\mu g} = \sqrt{v^2}$$

$$v = \sqrt{r\mu g}$$

path 1: $v = \sqrt{(400)(1.0)(9.8)}$

$= 62.6 \text{ m/s}$

path 2: $v = \sqrt{(800)(1.0)(9.8)}$

$= 88.5 \text{ m/s}$

$$\boxed{\begin{array}{l}\text{velocity of car on path 1 is 62.6 m/s.}\\ \text{Velocity of car on path 2 is 88.5 m/s.}\end{array}}$$

④ Two bonus points: The existence of the dwarf planet Pluto was proposed based on irregularities in Neptune's orbit. Pluto was subsequentially discovered near its predicted position. But now it appears that the discoveny was fortuitous, because Pluto is small and the irregularities in Neptune's orbit were not well known. To illustrate that Pluto has a minor effect on the orbit of Neptune compared to the closest planet to Neptune,

(a) Calculate the acceleration due to gravity at Neptune due to Pluto when they are 4.5×10^{12} m apart, as they are now. The mass of Pluto is 1.4×10^{22} kg.

Gravity above the earth's surface

$a_c = \frac{Gm}{r^2}$ $F_G = G\frac{m_1 m_2}{r^2}\hat{r}$ $g = G\frac{M_E}{r^2}$

Gravitational constant $= 6.67 \times 10^{-11} N \cdot m^2/k$

$a_c = \frac{(6.67 \times 10^{-11} N \cdot m^2/kg^2)(1.4 \times 10^{22} kg)}{(4.5 \times 10^{12} m)^2}$

$\boxed{a_c = 4.61 \times 10^{-14} m/s^2}$

(b) Now calculate the acceleration due to gravity at Neptune due to Uranus, presently about 2.5×10^{12} m apart, and compare it with that due to Pluto. The mass of Uranus is 8.62×10^{25} kg.

$a_c = \frac{Gm}{r^2} = \frac{(6.67 \times 10^{-11} N \cdot m^2/kg^2)(8.62 \times 10^{25} kg)}{(2.50 \times 10^{12} m)^2}$

$\boxed{a_c = 9.2 \times 10^{-10} m/s^2}$