



Announcements

- WebWork 7 due tonight!
- WebWork 8 due on Friday
- I'm working on getting my grade reporting system up and running so you can know where you stand currently in the class
- Polling: `rembold-class.ddns.net`



Review Question

A 10 g sheet of paper is blown horizontally against a vertical brick wall by a $\langle 5, 0, 0 \rangle$ N breeze. The coefficient of static friction between paper and brick is *roughly* (friction pun!) $\mu_s = 0.75$. Will the paper slide down the wall? You can assume you are on the surface of Earth.

- A. Yes. Yes the paper will slide.
- B. Nope! That paper is staying put.
- C. Jokes on you! That paper is moving *up* the wall.
- D. It is impossible to determine this without knowing the normal force of the wall on the paper.

$$E_3 = 3E_1$$

$$E_2 = 4E_1$$

$$E_1$$

$$d$$

$$x$$

$$h^2 = u^2 + E_1$$

$$|d\vec{E}| = \frac{1}{4\pi\epsilon_0} \frac{dq}{r^2}$$

$$= \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2}$$

$$dE_y = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{y}{r}$$

$$dE_x = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{x}{r}$$

$$d\vec{y} = |d\vec{E}| \cos \theta$$

$$d\vec{E}_x = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{x}{r}$$

$$d\vec{E}_y = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{y}{r}$$

$$\lambda_1 = \frac{u_1}{f}; \lambda_2 = \frac{u_2}{f}$$

$$\sin \theta_2 = \frac{\lambda_1}{\lambda_2} \sin \theta_1$$

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{\lambda_2}{\lambda_1} = \frac{u_1}{u_2} = \frac{v_1}{v_2}$$

$$U = F_e r = F_r \sin \theta = F_L$$

$$v = v_0 \sin \theta$$

$$F_n x + F_g x = m a$$

$$F_n x = 0; F_g x = F_n \sin \theta = m g \sin \theta$$

$$a_x = g \sin \theta$$

$$v^2 = 2 g h$$

$$v_s = \sqrt{2 g h} \sin \theta$$

$$v = v_0 \sin \theta$$

$$U_A, \phi = X \sin \theta$$

$$z = \sqrt{z^2 + x^2}$$

Upcoming:

Fluid Contact Forces

$$|U|^2 = A^2 \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

$$B(x) = \frac{\sigma}{\sqrt{\pi}} e^{-\sigma^2(x-x_0)^2}$$

$$e(\psi) = A \cos(\psi_0 x - \omega t)$$

$$|F| = \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

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

$$E_{pot} = -\frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$E_{kin} = \frac{1}{2} m v^2 = \frac{1}{2} \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$E_{pot} = -2 E_{kin}$$

$$E_{pot} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$F_2 = \frac{F_L}{2}$$

$$E = F_2 \cdot s$$

$$= \frac{F_L}{2} \cdot u \cdot h$$

$$F_L = F_L \cdot h$$

$$= m \cdot g \cdot h$$

$$s = u \cdot h$$

$$b = b_2 + \mu_0 u = b_2 (1 + \mu_0 u)$$

$$E = c b$$

$$= \mu_0 c b_2 u = \mu_0 c b_2 \int u du$$

$$m_1 v_{1x} + m_2 v_{2x} = m_1 v_{1x}' + m_2 v_{2x}'$$

$$\frac{1}{2} m_1 v_{1x}^2 + \frac{1}{2} m_2 v_{2x}^2 = \frac{1}{2} m_1 v_{1x}'^2 + \frac{1}{2} m_2 v_{2x}'^2$$

$$= \frac{1}{2} m_1 v_{1x}^2 + \frac{1}{2} m_2 v_{2x}^2$$

$$A'B' = \frac{s' - f}{f}$$

$$\frac{s'}{s} = \frac{s' - f}{f}$$

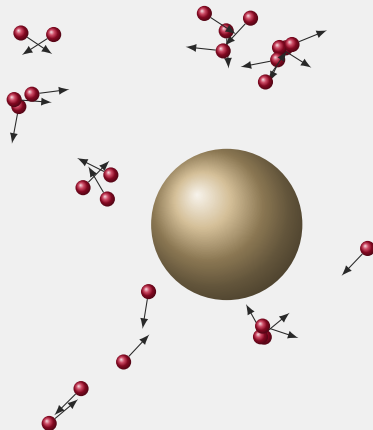
$$F_s = \frac{m g}{\cos \theta}$$

$$F_s = \frac{m g}{\sin \theta}$$



Bouncy Forces

- Contact Forces can take different forms
- Approximated solids with springs because of crystal-like structure
- Fluids (including gases) operate in a more free fashion
- Apply a contact force by bombarding a surface
 - Atoms/Molecules bounce back \Rightarrow change in momentum





Under Pressure

dum-dum-dum-da-da-dum-dum

- Total force applied depends on the area being struck by the atoms
- Define pressure as

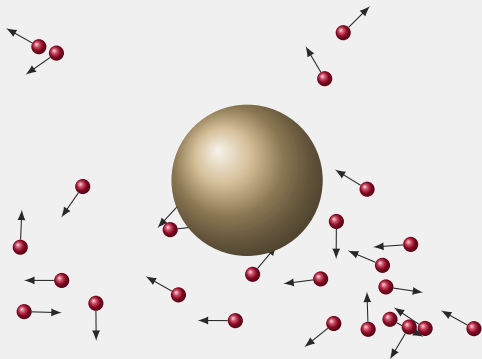
$$P = \frac{F}{A}$$

where A is the area being bombarded

- Standard unit is a N/m^2 or a Pascal (Pa)
- Can determine force due to pressure by multiplying the pressure by the area



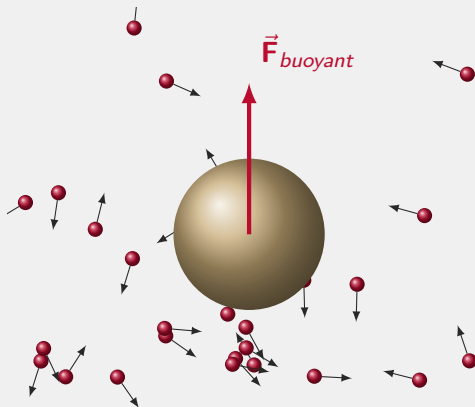
You Buoy Me Up



- In practice, gravity pushes more things towards the bottom
- More atoms \Rightarrow more bombardments \Rightarrow more pressure \Rightarrow greater force
- Bottom of object feels a greater force due to pressure than top
- Gives a net push upwards, called the buoyant force
- Magnitude of buoyant force equals the *weight* (mg or ρVg) of the displaced fluid



You Buoy Me Up

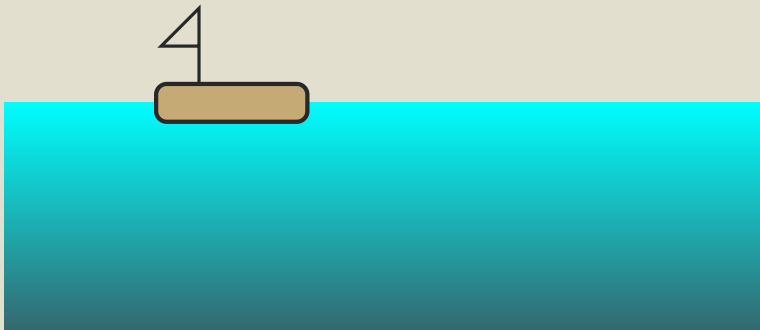


- In practice, gravity pushes more things towards the bottom
- More atoms \Rightarrow more bombardments \Rightarrow more pressure \Rightarrow greater force
- Bottom of object feels a greater force due to pressure than top
- Gives a net push upwards, called the buoyant force
- Magnitude of buoyant force equals the *weight* (mg or ρVg) of the displaced fluid



I'm on a BOAT

Suppose we have the (somewhat boring) rectangular boat below. The boat has a total mass of 800 kg and has a 2 m by 1 m bottom cross-section and sidewalls 50 cm high. Assuming we place the boat in water with a density of 1000 kg/m^3 , will the boat stay dry or fill with water?



$$E_3 = 3E_1$$

$$E_2 = 4E_1$$

$$E_1$$

$$d$$

$$x$$

$$h^2 = u^2 + v^2$$

$$u = 3$$

$$h = 4$$

$$v = 5$$

$$|d\mathbf{E}| = \frac{1}{4\pi\epsilon_0} \frac{dq}{r^2}$$

$$= \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2}$$

$$dE_y = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \sin\theta$$

$$dE_x = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \cos\theta$$

$$dE_y = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{y}{r}$$

$$dE_x = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{x}{r}$$

$$\lambda_1 = \frac{u_1}{f}$$

$$\lambda_2 = \frac{u_2}{f}$$

$$\sin\theta_1 = \frac{\lambda_1}{AB'}$$

$$\sin\theta_2 = \frac{\lambda_2}{AB'}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{u_1}{u_2} = \frac{v_1}{v_2}$$

$$U = F_e r = F_r \sin\theta = F_L$$

$$v = v_0 \sin\theta$$

$$F_n \cdot x + F_g \cdot x = m a$$

$$F_n \cdot x = 0$$

$$F_g \cdot x = F_g \sin\theta$$

$$= m g \sin\theta$$

$$a_x = g \sin\theta$$

$$v^2 = 2 g h$$

$$v_s = \sqrt{2 g h} \cdot \sin\theta$$

$$v = v_s \sin\theta$$

$$U_A, \phi = X \sin\theta$$

$$z = \sqrt{r^2 + x^2}$$

Upcoming:

From Motion: Forces

$$|U|^2 = A^2 \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

$$B(x) = \frac{\sqrt{x}}{\sqrt{\pi}} e^{-\sigma^2(x-x_0)^2}$$

$$U(\psi) = A \cos(k_0 x - \omega t)$$

$$|F| = \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

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

$$E_{pot} = -\frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$E_{kin} = \frac{1}{2} m v^2$$

$$= \frac{1}{2} \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$E_{pot} = -2 E_{kin}$$

$$F_2 = \frac{F_L}{2}$$

$$E = F_2 \cdot s$$

$$= \frac{F_L}{2} \cdot u \cdot h$$

$$F_L = F_L \cdot h$$

$$= m \cdot g \cdot h$$

$$s = u \cdot h$$

$$E_{pot} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$\frac{1}{s} = \frac{1}{s'} + \frac{1}{s''}$$

$$\frac{A'B'}{AB} = \frac{s'}{s}$$

$$v_1$$

$$v_2$$

$$v_3$$

$$v_4$$

$$v_5$$

$$v_6$$

$$v_7$$

$$v_8$$

$$v_9$$

$$v_{10}$$

$$v_{11}$$

$$v_{12}$$

$$v_{13}$$

$$v_{14}$$

$$v_{15}$$

$$v_{16}$$

$$v_{17}$$

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$$v_{96}$$

$$v_{97}$$

$$v_{98}$$

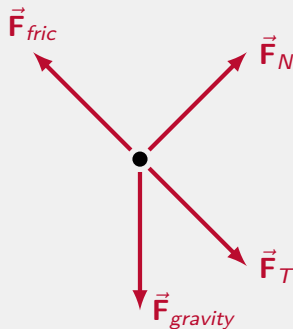
$$v_{99}$$

$$v_{100}$$



Do (or do not) Underestimate FBDs

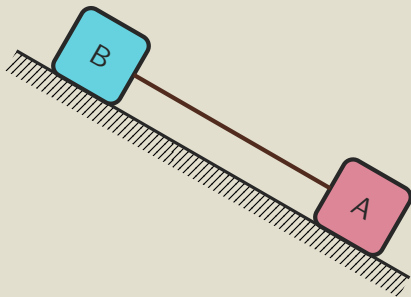
- Free body diagrams are going to be even more important to us going forwards
- Basic Steps:
 - Identify all objects in surroundings acting via a long-range force (gravity or electrically)
 - Identify all objects in surroundings acting via contact forces (tension, normal, friction, buoyancy, etc)
 - Draw your FBD, labeling all forces
- Remember that *you* choose the system, and FBD's on different systems will look different!





A Matter of Perspective

Consider two masses attached via a rope sliding down an incline. Draw FBD's for mass A, mass B, and a system consisting of both mass A and B. Assume they are on the surface of Earth and that the incline is rough.



$$E_3 = 3E_1$$

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$$E_1$$

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$$h^2 = u^2 + E_1^2$$

$$|d\vec{E}| = \frac{1}{4\pi\epsilon_0} \frac{dq}{r^2}$$

$$= \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2}$$

$$dE_y = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{y}{r}$$

$$dE_x = \frac{\lambda}{4\pi\epsilon_0} \frac{dx}{r^2} \frac{x}{r}$$

$$d\vec{y} = |d\vec{E}| \cos \theta$$

$$d\vec{y} = |d\vec{E}| \sin \theta$$

$$\cos \theta = \frac{y}{r}$$

$$\sin \theta = \frac{x}{r}$$

$$\lambda_1 = \frac{u_1}{f}$$

$$\lambda_2 = \frac{u_2}{f}$$

$$\sin \theta_1 = \frac{\lambda_1}{AB'}$$

$$\sin \theta_2 = \frac{\lambda_2}{AB'}$$

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{u_1}{u_2} = \frac{v_1}{v_2}$$

$$U = F_e r = F_r \sin \theta = F_L$$

$$v = v_0 \sin \theta$$

$$F_n x + F_g x = ma$$

$$F_n x = 0; F_g x = F_n \sin \theta$$

$$= mg \sin \theta$$

$$a_x = g \sin \theta$$

$$z = \sqrt{z^2 + x^2}$$

$$v^2 = 2gh$$

$$v_s = \sqrt{2gh} \sin \theta$$

$$\Delta P = c \rho A (T_4 - T_0)$$

$$U_A, U_B = X_C \dot{\theta}$$

$$V = v \sin \theta$$

Constant Motion

$$|U|^2 = A^2 \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

$$B(x) = \frac{\sqrt{x}}{\sqrt{\pi}} e^{-\sigma^2(x-x_0)^2}$$

$$U(\psi) = A \cos(k_0 x - \omega t)$$

$$|F| = \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

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$$E_{pot} = -\frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$E_{kin} = \frac{1}{2} mv^2$$

$$= \frac{1}{2} \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$E_{pot} = -2E_{kin}$$

$$E_{pot} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$\frac{1}{s} = \frac{1}{s'} + \frac{1}{s''}$$

$$F_2 = \frac{F_L}{2}$$

$$E = F_2 \cdot s$$

$$= \frac{F_L}{2} \cdot u \cdot h$$

$$F_L = F_L \cdot h$$

$$= m \cdot g \cdot h$$

$$s = u \cdot h$$

$$b = b_2 + \mu_0 U = b_2 (1 + \lambda_{mag})$$

$$E = cB$$

$$= \mu_0 c^2 h J = \mu_0 J$$

$$m_1 v_{1x} + m_2 v_{2x} = m_1 v_{1x}' + m_2 v_{2x}'$$

$$\frac{1}{2} m_1 v_{1x}^2 + \frac{1}{2} m_2 v_{2x}^2 = \frac{1}{2} m_1 v_{1x}'^2 + \frac{1}{2} m_2 v_{2x}'^2$$

$$= \frac{1}{2} m_1 v_{1x}^2 + \frac{1}{2} m_2 v_{2x}^2$$

$$A'B' = \frac{s' - f}{f}$$

$$\frac{s'}{s} = \frac{s' - f}{f}$$

$$F_s = \frac{mg}{\cos \theta}$$

$$\tan \theta = \frac{ax}{g}$$

$$F_s = \frac{mg}{\cos \theta}$$

$$U_H = -\int \vec{B} \cdot (d\vec{V})$$

$$U_H = E_H b = v d B b$$

$$J = \frac{n}{V} q v d A$$

$$b \frac{U}{V} = \frac{1}{A q v b} \int b d v d$$

$$= -\int \vec{B} \cdot d\vec{U}_H$$

$$E_{pot} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$A'B' = \frac{s'}{s}$$

$$V_1 \rightarrow V_2$$

$$m_1 v_{1x} + m_2 v_{2x} = m_1 v_{1x}' + m_2 v_{2x}'$$

$$\frac{1}{2} m_1 v_{1x}^2 + \frac{1}{2} m_2 v_{2x}^2 = \frac{1}{2} m_1 v_{1x}'^2 + \frac{1}{2} m_2 v_{2x}'^2$$

$$E_{pot} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

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$$U_H = E_H b = v d B b$$

$$J = \frac{n}{V} q v d A$$

$$b \frac{U}{V} = \frac{1}{A q v b} \int b d v d$$

$$= -\int \vec{B} \cdot d\vec{U}_H$$



Constant Considerations

- Motion is constant when:
 - Direction is unchanging
 - Velocity is unchanging
- As such, in this situation $\Delta \vec{p} = 0$, or, put in our new formulation:

$$\frac{d\vec{p}}{dt} = 0$$

- Thus we will be starting from situations where

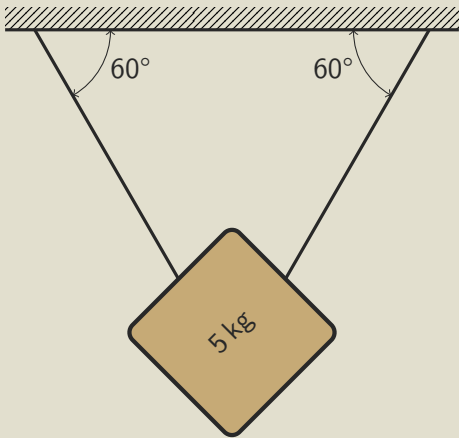
$$\vec{F}_{net} = \vec{0} = \langle 0, 0, 0 \rangle$$

- This sort of analysis is also called *statics*
- Time for a lot of examples!



Hanging Masses

Suppose the block below is hanging from two separate strings that form interior angles of 60° with the ceiling. What is the tension in each string?





Practice Time!

Two sleds connected via a rope are sliding down a 20° incline at a constant rate. The lower sled ($m=10\text{ kg}$) is very slippery and experiences no frictional force, while the upper sled ($m=40\text{ kg}$) has a non-zero but unknown coefficient of kinetic friction.

- What is the tension in the rope?
- If the rope measures 1 mm in diameter and 2 m long, how much does it stretch?
You can assume the rope is made of hemp with a Young's Modulus of 35 GPa.
- What is the coefficient of kinetic friction between the upper sled and the snow?
You can take the rope to have negligible mass.