FORCES AND UNIFORM CIRCULAR MOTION

PHYSICS

UNIT 2

Physics Unit 2

- This Slideshow was developed to accompany the textbook
  - *OpenStax Physics*
    - *Available for free at https://openstaxcollege.org/textbooks/college-physics*
  - *By OpenStax College and Rice University*
  - *2013 edition*
- Some examples and diagrams are taken from the *OpenStax Physics* and *Cutnell & Johnson Physics* 6th ed.

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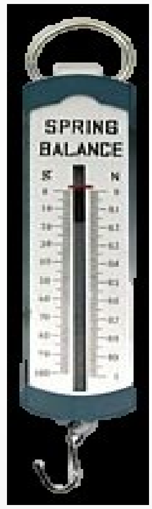
02-01 NEWTON’S LAWS OF MOTION

In this lesson you will…

- Understand the definition of force.
- Define mass and inertia.
- Understand Newton's first law of motion.
- Define net force, external force, and system.
- Understand Newton’s second law of motion.
- Understand Newton's third law of motion.

02-01 NEWTON'S LAWS OF MOTION

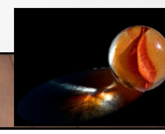
- Kinematics
  - How things move
- Dynamics
  - Why things move



- Force
  - A push or a pull
  - Is a vector
  - Unit: Newton (N)
  - Measured by a spring scale

02-01 NEWTON'S LAWS OF MOTION

1. Place a marble on your desk so that it is at rest (not moving).
2. Observe the marble for a minute. What happens to it?
3. Without applying a force to the marble, make it move. Remember gravity is a force, so tipping the desk is the same as applying a force. Were you able to move the marble?
4. Roll the marble across your desk at a moderate speed so that it has no sidewise spin. Describe the path the marble took.
5. Without a sidewise spin, tipping the desk, or applying a force, can you make the marble take a curved path?



2. Nothing
3. No
4. Straight
5. No

02-01 NEWTON'S LAWS OF MOTION

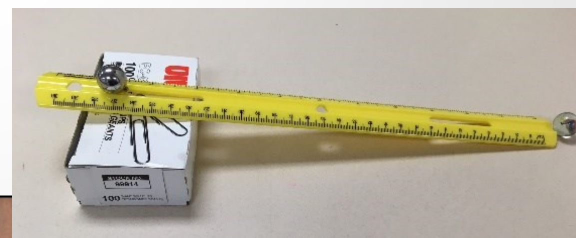
Newton's First Law of Motion

- A body at rest remains at rest, or, if in motion, remains in motion at a constant velocity unless acted on by a net external force.
- Inertia
  - Property of objects to remain in constant motion or rest.
  - Mass is a measure of inertia
  - Watch Eureka! 01
  - Watch Eureka! 02

Example: Ice hockey, puck sits until someone hits it. Then it goes straight.

02-01 NEWTON'S LAWS OF MOTION

1. Make a ramp using the grooved ruler and a book.
2. Place a glass marble on your desk at the end of the ramp.
3. Release the other glass marble from the top of the ramp so that it rolls and hits the marble on the desk. Observe the velocity of the marble that was on the desk.
4. Place a glass marble on the desk at the end of the ramp.
5. Release the metal marble from the top of the ramp so that it rolls and hits the metal marble on the desk. Observe the velocity of the metal marble.
6. Which marble on the desk (1st or 2nd) had a larger force applied to it?
7. Which marble had the larger final velocity?
8. What was the marble's initial velocity in both cases?
9. Define acceleration.
10. Which marble had the larger acceleration?
11. What is the relationship between force and acceleration?



6. 2nd
7. 2nd
8. 0
9. $a = \frac{\Delta v}{\Delta t}$
10. 2nd
11. Bigger force = bigger acceleration

02-01 NEWTON'S LAWS OF MOTION

1. Place a glass marble on your desk at the end of the ramp.
2. Release the other glass marble from the top of the ramp so that it rolls and hits the marble on the desk. Observe the velocity of the marble that was on the desk.
3. Place a metal marble on the desk at the end of the ramp.
4. Release the glass marble from the top of the ramp so that it rolls and hits the metal marble on the desk. Observe the velocity of the metal marble.
5. Which marble on the desk (glass or metal) had a larger force applied to it?
6. Which marble had the larger final velocity?
7. Which marble had the larger acceleration?
8. Which marble had more mass?
9. What is the relationship between mass and acceleration?

5. Same
6. Glass
7. Glass
8. Metal
9. Bigger mass = smaller acceleration

02-01 NEWTON'S LAWS OF MOTION

Newton's Second Law of Motion

- Acceleration of a system is directly proportional to and in the same direction as the net force acting on the system, and inversely proportional to its mass.

$$\boldsymbol{F}_{net} = m\boldsymbol{a}$$

- Net force is the vector sum of all the forces.
- Watch Eureka! 03
- Watch Eureka! 04
- Watch Eureka! 05

02-01 NEWTON'S LAWS OF MOTION

1. Take two spring scales and hook their ends together. Lay them horizontally on the desk.
2. Gently pull on one spring scale so it reads 4 N.
3. What do the scales read for the force?
4. Apply 3-N force. What do the scales read?
5. With the scales hooked together, try to pull only one scale so that the other one does not experience a force. Were you successful, explain.

3. 4 N, 4 N
4. 3 N, 3 N
5. No (there is some friction involved in the spring scales and that can cause unequal force readings)

02-01 NEWTON'S LAWS OF MOTION

Newton's Third Law of Motion

- Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts.
- Every force has an equal and opposite reaction force.
- You push down on your chair, so the chair pushed back up on you.

02-01 NEWTON'S LAWS OF MOTION

- A football player named Al is blocking a player on the other team named Bob. Al applies a 1500 N force on Bob. If Bob's mass is 100 kg, what is his acceleration?
- What is the size of the force on Al?
- If Al's mass is 75 kg, what is his acceleration?

$$\boldsymbol{F = ma}$$
$$\boldsymbol{1500\ N = (100\ kg)a \rightarrow a = 15\ m/s^2}$$

1500 N (Newton's 3rd Law)

$$\boldsymbol{F = ma}$$
$$\boldsymbol{1500\ N = (75\ kg)a \rightarrow a = 20\ m/s^2}$$

02-01 NEWTON'S LAWS OF MOTION

- A 0.046 kg golf ball hit by a driver can accelerate from rest to 67 m/s in 1 ms while the driver is in contact with the ball. How much average force does the golf ball experience?

$$v = at + v_0$$
$$67\frac{m}{s} = a(1 \times 10^{-3}\ s) + 0$$
$$67000\frac{m}{s^2} = a$$
$$F = ma$$
$$F = (0.046\ kg)\left(67000\frac{m}{s^2}\right)$$
$$F = 3082\ N$$

02-01 NEWTON'S LAWS OF MOTION

- Force yourself to do these problems
- Read 4.5, 4.6, 6.5

02-02 WEIGHT AND GRAVITY

In this lesson you will…

- Define normal force.
- Apply Newton's laws of motion to solve problems involving a variety of forces.
- Use trigonometric identities to resolve weight into components.
- Understand and apply a problem-solving procedure to solve problems using Newton's laws of motion.
- Explain Earth’s gravitational force.

02-02 WEIGHT AND GRAVITY

- Weight
  - Measure of force of gravity
  - $F = ma$
  - Objects near earth accelerate downward at 9.80 m/s^2
  - $w = mg$
  - Unit: N
  - Depends on local gravity
- Mass
  - Not a force
  - Measure of inertia or amount of matter
  - Unit: kg
  - Constant
  - Watch Eureka! 6

02-02 WEIGHT AND GRAVITY

- Every particle in the universe exerts a force on every other particle

$$F_g = G\frac{mM}{r^2}$$

- $G = 6.673 \times 10^{-11}\ N\ m^2/kg^2$
- m and M are the masses of the particles
- r = distance between the particles (centers of objects)

G is the universal gravitational constant – measured by Henry Cavendish using a very sensitive balance 100 years after Newton proposed the law

02-02 WEIGHT AND GRAVITY

- For bodies
- Using calculus – apply universal gravitation for bodies
- Estimate (quite precisely)
  - Assume bodies are particles based at their center of mass
  - For spheres assume they are particles located at the center

02-02 WEIGHT AND GRAVITY

- What is the gravitational attraction between a 75-kg boy (165 lbs) and the 50-kg girl (110 lbs) seated 1 m away in the next desk?

- $F_g = 2.5 \times 10^{-7}$ N
  - $= 2.6 \times 10^{-8}$ lbs of force

$$m_1 = 75\ kg;\ m_2 = 50\ kg;\ r = 1\ m$$

$$F_g = \frac{GMm}{r^2}$$

$$F = \frac{6.67 \times 10^{-11} \frac{Nm^2}{kg^2} \left(75\ kg\right)\left(50\ kg\right)}{\left(1\ m\right)^2}$$

$$= 2.5 \times 10^{-7}\ N$$

02-02 WEIGHT AND GRAVITY

- Weight is Gravitational Force the earth exerts on an object
- Unit: Newton (N)
- Remember!!!
  - Weight is a Force
- Watch Eureka 7

Eureka #7

02-02 WEIGHT AND GRAVITY

- Weight

$$W = G\frac{mM}{r^2}$$

$$W = mg$$

$$g = G\frac{M}{r^2}$$

- r is usually R_E
  - So g = 9.80 m/s^2

02-02 WEIGHT AND GRAVITY

- The gravitational pull from the moon and sun causes tides
  - Water is pulled in the direction of the moon and sun

- Gravitational pull from satellites causes the main body to move slightly
  - Moon causes earth to move
  - Planets cause sun/star to move

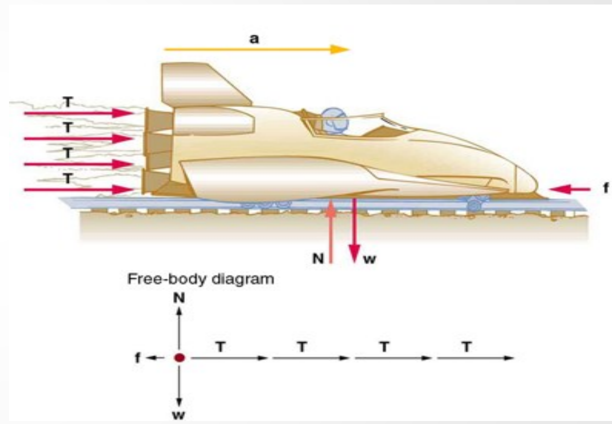
02-02 WEIGHT AND GRAVITY

- Problems-Solving Strategy

1. Identify the principles involved and draw a picture
2. List your knowns and Draw a free-body diagram
3. Apply $F_{net} = ma$
4. Check your answer for reasonableness

02-02 WEIGHT AND GRAVITY

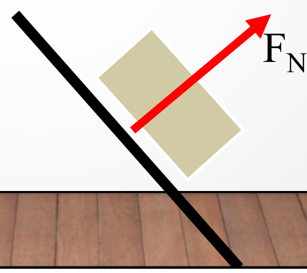
- Free-body diagram
  - Draw only forces acting on the object
  - Represent the forces with vector arrows



02-02 WEIGHT AND GRAVITY

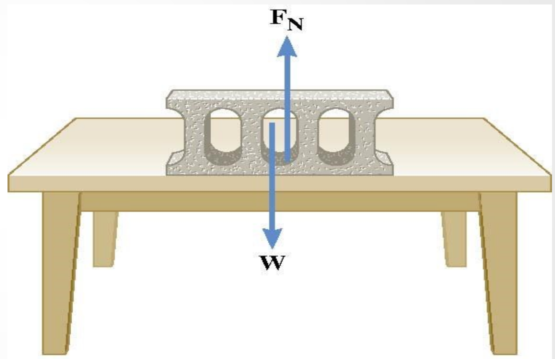
- When two objects touch there is often a force

- Normal Force
  - Perpendicular component of the contact force between two objects



02-02 WEIGHT AND GRAVITY

- Weight pushes down
- So the table pushes up
  - Called Normal force
  - Newton's 3rd Law



- Normal force doesn't always = weight
- Draw a freebody diagram to find equation

02-02 WEIGHT AND GRAVITY

1. Hang the mass from the spring scale. The scale will measure the force applied to hold the mass in place. This is the weight.
2. What is the weight of your mass?
3. Carefully watch the spring scale as you quickly move the scale upwards. What happens to the weight?
4. Carefully watch the spring scale as you quickly move the scale downwards. What happens to the weight?
5. The other weights are called apparent weight and is what you feel as the net force pulling you down. An upward acceleration produces a ____________________ apparent weight. A downward acceleration produces a ____________________ apparent weight.

- When a problem asks for apparent weight, find the normal force

3. More
4. Less
5. larger; smaller

02-02 WEIGHT AND GRAVITY

- A lady is weighing some bananas in a grocery store when the floor collapses. If the bananas mass is 2 kg and the floor is accelerating at -2.25 m/s^2, what is the apparent weight (normal force) of the bananas?

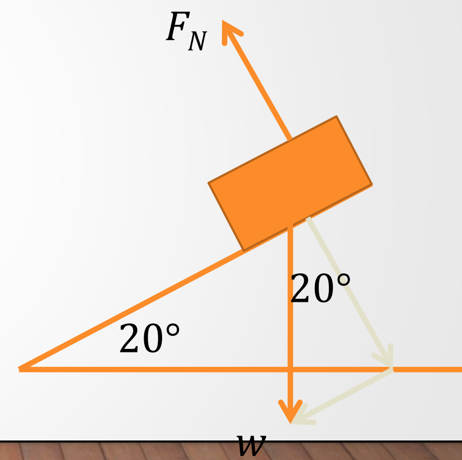
- F_N = 15.1 N

Draw freebody diagram and solve

$$F_{net} = F_N - w = ma$$
$$F_N - (2\ kg)\left(9.8\frac{m}{s^2}\right) = (2\ kg)\left(-2.25\frac{m}{s^2}\right)$$
$$F_N = 15.1\ N$$

02-02 WEIGHT AND GRAVITY

- A box is sitting on a ramp angled at 20°. If the box weighs 50 N, what is the normal force on the box?



- 47 N

$$w_\perp = w \cdot \cos 20° = 47\ N$$
$$F_N - w_\perp = ma = 0$$
$$F_N = w_\perp = 47\ \text{N}$$

02-02 WEIGHT AND GRAVITY

- Just like gravity, these problems are attractive.
- Read 5.1

02-03 FRICTION

In this lesson you will…

- Discuss the general characteristics of friction.
- Describe the various types of friction.
- Calculate the magnitude of static and kinetic friction.

02-03 FRICTION

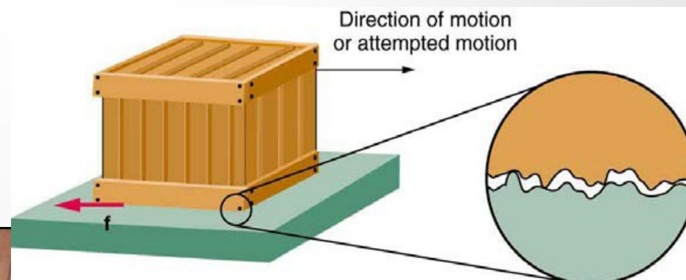
- Do the lab in your worksheet
- How is friction reduced in car engines? Hovercraft?

Oil to make it smoother
No mass on ground, so no normal force

02-03 FRICTION

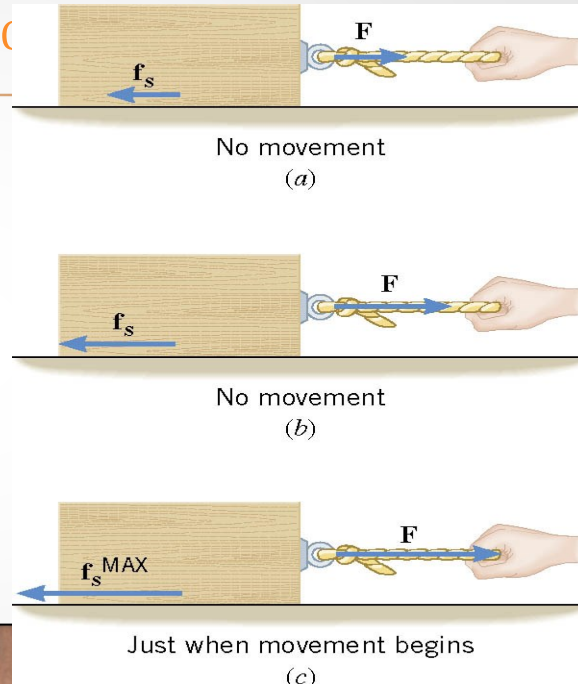
- Normal force – perpendicular to surface
- Friction force – parallel to surface, and opposes motion

- Comes from rough surface
- Not well understood



02-03 FRIC

- Static Friction
  - Keeps things from moving.
  - Cancels out applied force until the applied force gets too big.
  - Depends on force pushing down and roughness of surface



02-03 FRICTION

- Static Friction
  - Depends on force pushing down and roughness of surface
- $f_S \leq \mu_S F_N$
  - More pushing down (F_N), more friction
  - μ_S is coefficient of static friction (0.01 to 1.5)

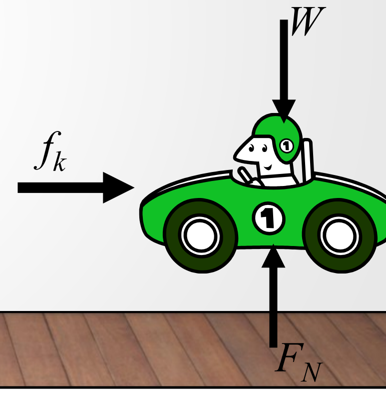
02-03 FRICTION

- Kinetic Friction
  - Once motion happens
  - $f_k = \mu_k F_N$
  - f_k is usually less than f_s

02-03 FRICTION

- A car skids to a stop after initially going 30.0 m/s. μ_k = 0.800. How far does the car go before stopping?

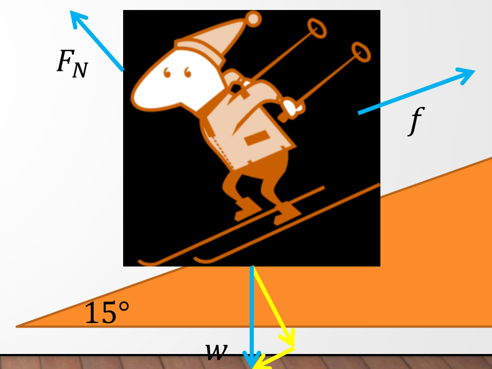
- 57.3 m



$$y:\ F_N = W = mg$$
$$x:\ f_k = \mu_k F_N = \mu_k mg$$
$$F = ma$$
$$\mu_k mg = ma \rightarrow\ \mu_k g = a$$
$$v^2 = v_0^2 + 2ax \rightarrow\ v^2 = v_0^2 + 2\mu_k gx$$
$$0 = \left(30.0\frac{m}{s}\right)^2 + 2(0.800)\left(-9.80\frac{m}{s^2}\right)x$$
$$-900\left(\frac{m}{s}\right)^2 = \left(15.7\frac{m}{s^2}\right)x \rightarrow x = 57.3\ m$$

02-03 FRICTION

- A 65-kg skier is coasting downhill on a 15° slope. Assuming the coefficient of friction is that of waxed wood on snow, what is the skier's acceleration?
- 1.59 m/s^2 downhill



Perpendicular direction:

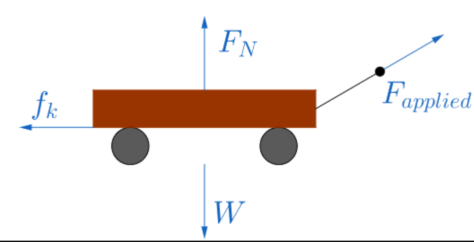
$$F_N - w\cos 15° = ma$$
$$F_N - mg\cos 15° = m(0)$$
$$F_N - (65\ kg)\left(9.8\frac{m}{s^2}\right)\cos 15° = 0$$
$$F_N = 615.2948\ N$$

parallel direction:

$$f - w\sin 15° = ma$$
$$\mu_k F_N - mg\sin 15° = ma$$
$$(0.1)(615.2948\ N) - (65\ kg)\left(9.8\frac{m}{s^2}\right)\sin 15° = (65\ kg)a$$
$$-103.338\ N = (65\ kg)a$$
$$-1.59\frac{m}{s^2} = a$$

02-03 FRICTION

- While hauling firewood to the house, you pull a 100-kg wood-filled wagon across level ground at a constant velocity. You pull the handle with a force of 230 N at 30° above the horizontal. What is the coefficient of friction between the wagon and the ground?



$$y: F_N - W + 230\ N \sin 30° = ma$$
$$F_N - (100\ kg)\left(9.8\frac{m}{s^2}\right) + 115\ N = (100\ kg)(0)$$
$$F_N = 865\ N$$

$$x: 230\ N \cos 30° - f_k = ma$$
$$199.1858\ N - \mu_k F_N = ma$$
$$199.1858\ N - \mu_k(865\ N) = (100\ kg)(0)$$
$$199.1858\ N = (865\ N)\mu_k$$
$$\mu_k = 0.230$$

02-03 FRICTION

- Don’t let these problems cause friction between us
- Read 4.5, 5.2, 4.7

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

In this lesson you will…

- Define tension force.
- Apply Newton's laws of motion to solve problems involving a variety of forces.
- Express mathematically the drag force.
- Discuss the applications of drag force.
- Define terminal velocity.
- Determine the terminal velocity given mass.
- Apply problem-solving techniques to solve for quantities in more complex systems of forces.

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- Do the lab on your worksheet

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- Hooke's Law
  - For springs or forces that deform (change shape)
  - For small deformations (no permanent change)
  - $F_S = k\Delta x$
    - $k =$ spring constant and is unique to each spring
    - $\Delta x =$ the distance the spring is stretched/compressed
  - Hooke's Law is the reason we can use a spring scale to measure force

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- Tension
  - Pulling force from rope, chain, etc.
  - Everywhere the rope connects to something, there is an identical tension

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- Drag
  - Resistive force from moving through a fluid
  - Size depends on area, speed, and properties of the fluid
- For large objects
  - $F_D = \frac{1}{2} C \rho A v^2$
  - C = drag coefficient
  - ρ = density of fluid
  - A = cross-sectional area of object
  - v = speed of object relative to the fluid

Fluids are liquids and gases

Area – think of your have outside of car window

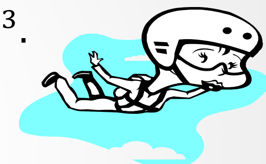
C = drag coefficient measured by experiment, table 5.2

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- Equilibrium
  - No acceleration
  - $F_{net} = ma$
  - $F_{net} = 0$

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- Find the terminal velocity of a falling mouse in air ($A = 0.004\ m^2, m = 0.02\ kg, C = 0.5$) and a falling human falling flat ($A = 0.7\ m^2, m = 85\ kg, C = 1.0$). The density of air is $1.21\ kg/m^3$.



- Mouse: 12.7 m/s
- Human: 44.4 m/s

$$F_D - w = 0$$

$$\frac{1}{2} C \rho A v^2 = mg$$

$$v = \sqrt{\frac{2mg}{\rho C A}}$$

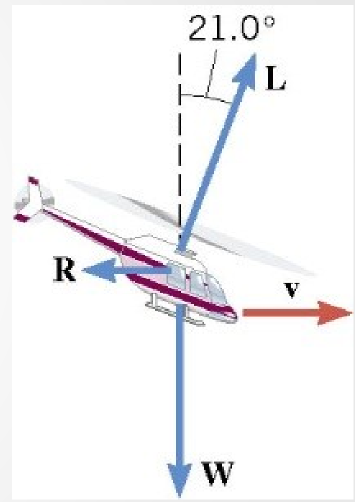
Mouse: $v = \sqrt{\frac{2(0.02\ kg)\left(9.8\frac{m}{s^2}\right)}{\left(1.21\frac{kg}{m^3}\right)(0.5)(0.004\ m^2)}} = 12.7\frac{m}{s}$

Human: $v = \sqrt{\frac{2(85\ kg)\left(9.8\frac{m}{s^2}\right)}{\left(1.21\frac{kg}{m^3}\right)(1.0)(0.7\ m^2)}} = 44.4\frac{m}{s}$

Mice bounce after big falls, but humans break

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- The helicopter in the drawing is moving horizontally to the right at a constant velocity. The weight of the helicopter is 53,800 N. The lift force **L** generated by the rotating blade makes an angle of 21.0° with respect to the vertical. What is the magnitude of the lift force?
- 57600 N

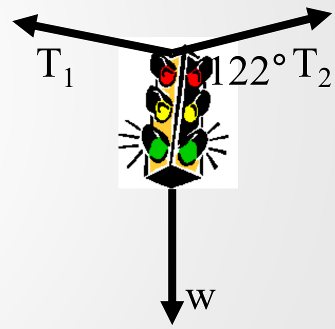


y-components

$$L \cos 21.0° - W = ma$$
$$L \cos 21.0° - 53800\ N = 0$$
$$L \cos 21.0° = 53800\ N$$
$$L = 57600\ N$$

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- A stoplight is suspended by two cables over a street. Weight of the light is 110 N and the cables make a 122° angle with each side of the light. Find the tension in each cable.



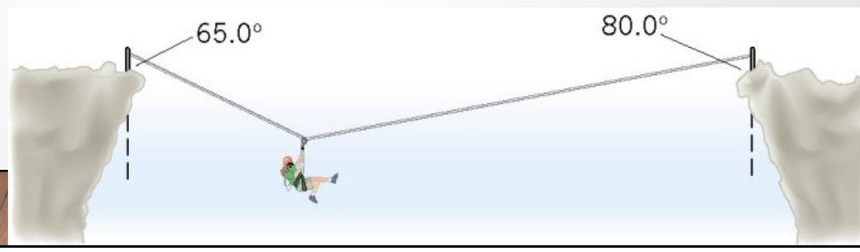
- 104 N

Solve on board by making a table

$$F_x\!: \ T_2 \cos 32° - T_1 \cos 32° = 0$$
$$T_2(.8480) - T_1(.8480) = 0$$
$$T_1 = T_2$$
$$F_y\!: -w + T_1 \sin 32° + T_2 \sin 32° = 0$$
$$-110\ N + T_1(.5299) + T_2(.5299) = 0$$
$$-110\ N + 1.0598 T_1 = 0$$
$$1.0598\, T_1 = 110\ N$$
$$T_1 = T_2 = 103.8\ N$$

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- A mountain climber, in the process of crossing between two cliffs by a rope, pauses to rest. She weighs 535 N. Find the tensions in the rope to the left and to the right of the mountain climber.



x-direction

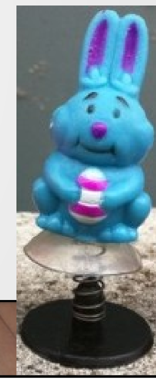
$$-T_1 \sin 65° + T_2 \sin 80° = ma = 0$$
$$T_2 = 0.920289 T_1$$

y-direction

$$T_1 \cos 65° + T_2 \cos 80° - w = ma = 0$$
$$T_1 \cos 65° + (0.9202889 T_1) \cos 80° - 535\ N = 0$$
$$0.582424777 T_1 = 535\ N$$
$$T_1 = 919\ N$$
$$T_2 = 845\ N$$

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- A 10-g toy plastic bunny is connected to its base by a spring. The spring is compressed and a suction cup on the bunny holds it to the base so that the bunny doesn't move. If the spring is compressed 3 cm and has a constant of 330 N/m, how much force must the suction cup provide?



$$F_S - w - F_{cup} = ma = 0$$
$$kx - mg - F_{cup} = 0$$
$$\left(330\,\frac{N}{m}\right)(0.03\,m) - (0.010\,kg)\left(9.8\,\frac{m}{s^2}\right) - F_{cup} = 0$$
$$F_{cup} = 9.8\,N$$

02-04 TENSION, HOOKE'S LAW, DRAG, AND EQUILIBRIUM

- The tension is mounting… I can't wait to see what's next!
- Read 4.8

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

In this lesson you will…

- Understand the four basic forces that underlie the processes in nature.

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

- Four Basic Forces
  - All forces are made up of only 4 forces
  - Gravitational - gravity
  - Electromagnetic – static electricity, magnetism
  - Weak Nuclear - radioactivity
  - Strong Nuclear – keeps nucleus of atoms together

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

- All occur because particles with that force property play catch with a different particle
  - Electromagnetic uses photons
  - Scientists are trying to combine all forces together in Grand Unified Theory
  - Have combined electric, magnetic, weak nuclear

- Gravity is the weakest
  - We feel it because the electromagnetic cancels out over large areas
- Nuclear forces are strong but only over short distance

Close on combining gravitational too

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

- A 1380-kg car is moving due east with an initial speed of 27.0 m/s. After 8.00 s the car has slowed down to 17.0 m/s. Find the magnitude and direction of the net force that produces the deceleration.

Use kinematics to find *a*

$$v_0 = 27.0\frac{m}{s}, t = 8.00\ s, v = 17.0\frac{m}{s}, a = ?$$

$$v = at + v_0$$

$$17\frac{m}{s} = a(8\ s) + 27\frac{m}{s}$$

$$a = -1.25\frac{m}{s^2}$$

Use Newton's 2nd Law

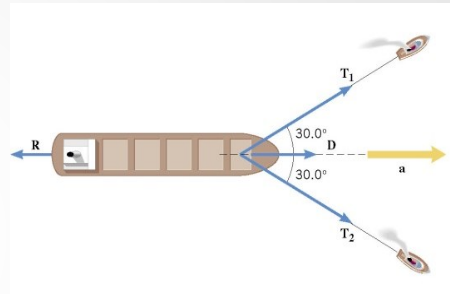
$$F = ma$$

$$F = (1380\ kg)\left(-1.25\frac{m}{s^2}\right) = -1725\ N$$

1725 N West

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

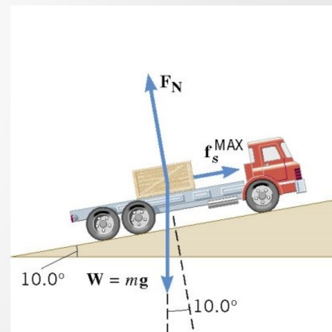
- A supertanker of mass $m = 1.50 \times 10^8$ kg is being towed by two tugboats, as in the picture. The tensions in the towing cables apply the forces T_1 and T_2 at equal angles of 30.0° with respect to the tanker's axis. In addition the tanker's engines produce a forward drive force D, whose magnitude is $D = 75.0 \times 10^3$ N. Moreover, the water applies an opposing force R, whose magnitude is $R = 40.0 \times 10^3$ N. The tanker moves forward with an acceleration of 2.00×10^{-3} m/s². Find the magnitudes of the tensions T_1 and T_2.



$$F_{net} = ma$$
$$y: T_1 \sin 30° - T_2 \sin 30° = ma = 0$$
$$T_1 = T_2$$
$$x: T_1 \cos 30° + T_2 \cos 30° + D - R = ma$$
$$T_1\left(\frac{\sqrt{3}}{2}\right) + T_1\left(\frac{\sqrt{3}}{2}\right) + 75 \times 10^3\ N - 40.0 \times 10^3\ N$$
$$= (1.50 \times 10^8\ kg)\left(2.00 \times 10^{-3}\ \frac{m}{s^2}\right)$$
$$\sqrt{3}T_1 = 2.65 \times 10^5\ N$$
$$T_1 = T_2 = 1.53 \times 10^5\ N$$

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

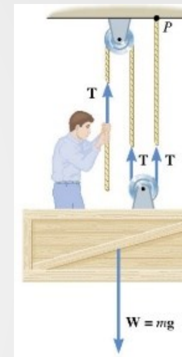
- A flatbed truck is carrying a crate up a 10.0° hill as in the picture. The coefficient of the static friction between the truck bed and the crate is $\mu_s = 0.350$. Find the maximum acceleration that the truck can attain before the crate begins to slip backward relative to the truck.



$$F_{net} = ma$$
$$y: F_N - w\cos 10° = ma = 0$$
$$F_N = mg\cos 10°$$
$$x: f_s - w\sin 10° = ma$$
$$\mu_s F_N - mg\sin 10° = ma$$
$$0.350(\cancel{m}g\cos 10°) - \cancel{m}g\sin 10° = \cancel{m}a$$
$$1.68\frac{m}{s^2} = a$$

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

- A window washer on a scaffold is hoisting the scaffold up the side of a building by pulling downward on a rope, as in the picture. The magnitude of the pulling force is 540 N, and the combined mass of the worker and the scaffold is 155 kg. Find the upward acceleration of the unit.



$$3T - w = ma$$
$$3(540\ N) - (155\ kg)\left(9.8\frac{m}{s^2}\right) = (155\ kg)a$$
$$0.65\frac{m}{s^2} = a$$

02-05 NONEQUILIBRIUM AND FUNDAMENTAL FORCES

- Electromagnetic forces are responsible for doing homework.

- Read 6.1, 6.2

02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

In this lesson you will…

- Define arc length, rotation angle, radius of curvature and angular velocity.
- Calculate the angular velocity of a car wheel spin.
- Establish the expression for centripetal acceleration.
- Explain the centrifuge.

02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Newton's Laws of motion primarily relate to straight-line motion.
- Uniform Circular Motion
  - Motion in circle with constant speed
- Rotation Angle ($\Delta\theta$)
  - Angle through which an object rotates

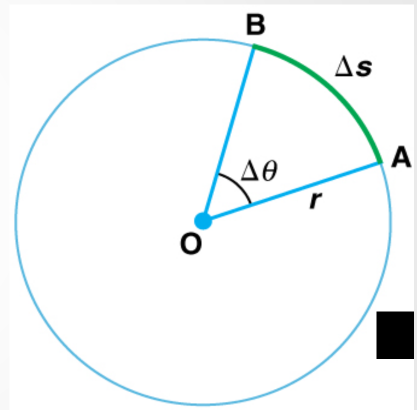
02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Arc Length is the distance around part of circle

$$\Delta\theta = \frac{\Delta \boldsymbol{s}}{\boldsymbol{r}}$$

- Angle Units:
  - Revolutions: 1 circle = 1 rev
  - Degrees: 1 circle = 360°
  - Radians: 1 circle = 2π
- Arc Length formula must use radians and angle unit

$$2\pi = 360° = 1\, rev$$



02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Convert 60° to radians
- Convert 2 revolutions to radians

$$\frac{60°}{}\left(\frac{2\pi}{360°}\right) = \frac{\pi}{3}$$

$$\frac{2\ rev}{}\left(\frac{2\pi}{1\ rev}\right) = 4\pi$$

02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Angular Velocity (ω)
  - How fast an object rotates

$$\omega = \frac{\Delta\theta}{\Delta t}$$

- Unit: rad/s
  - CCW +, CW –

$$v = \frac{\Delta s}{\Delta t}$$

$$\Delta\theta = \frac{\Delta s}{r} \rightarrow \Delta s = r\Delta\theta$$

$$v = \frac{r\Delta\theta}{\Delta t} = r\omega$$

02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

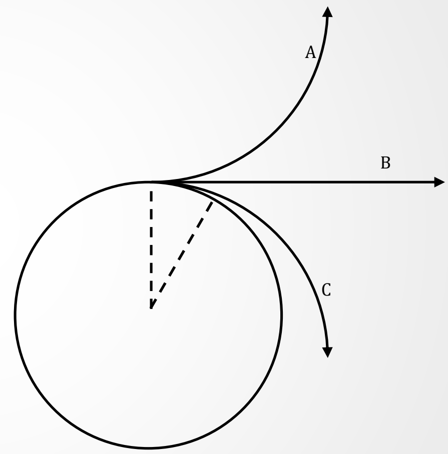
- A CD rotates 320 times in 2.4 s. What is its angular velocity in rad/s? What is the linear velocity of a point 5 cm from the center?

$$\theta = 320\,rev\,(2\pi/1\,rev) = 640\pi\,rad$$
$$t = 2.4s$$
$$\omega = \theta/t = 640\pi\,rad/2.4s = 838\,rad/s$$

$$v = r\omega$$
$$v = (0.05\,m)\left(838\frac{rad}{s}\right) = 41.9\,m/s$$

02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Make a hypothesis about what will happen. Which path will an object most closely follow when the centripetal force is removed?



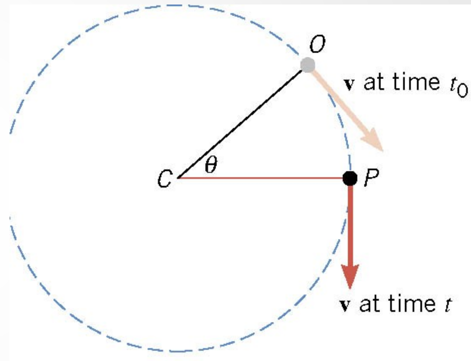
02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

1. Put the plate on a flat surface and put a marble in the ridge.
2. Push the marble in the ridge so that it travels around the plate and then out of the removed section.
3. What is providing the centripetal force? i.e. what is keeping the marble traveling in a circle?
4. Perform the test several times and record your results.
5. Which of Newton's Laws explains the results?
6. This would have been more complicated if the object moved in a vertical circle. Why?

3. Rim of the plate
4. Straight line (B)
5. 1st
6. Gravity would have pulled it down

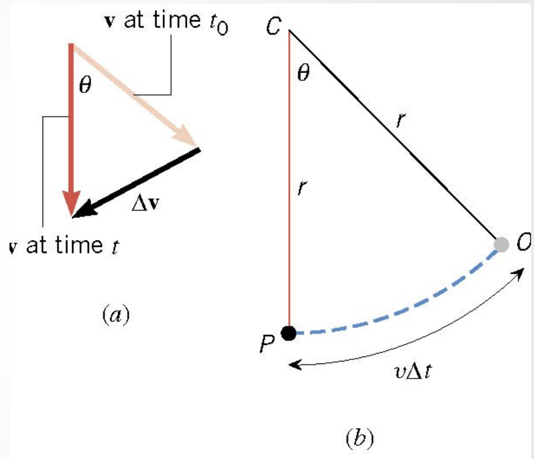
02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Object moves in circular path
- At time t_0 it is at point O with a velocity tangent to the circle
- At time t, it is at point P with a velocity tangent to the circle
- The radius has moved through angle θ



02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Draw the two velocity vectors so that they have the same tails.
- The vector connecting the heads is Δv
- Draw the triangle made by the change in position and you get the triangle in (b)



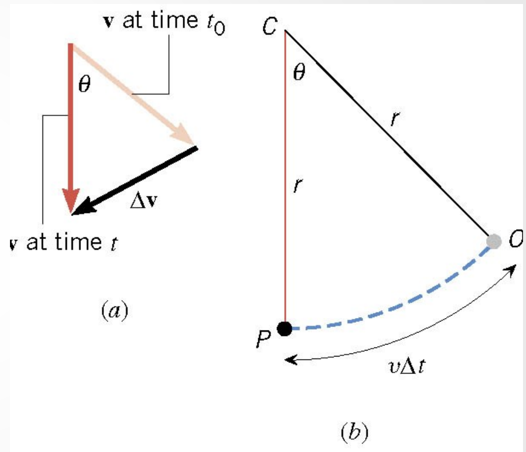
02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Since the triangles have the same angle are isosceles, they are similar.

$$\frac{\Delta v}{v} = \frac{v\Delta t}{r}$$

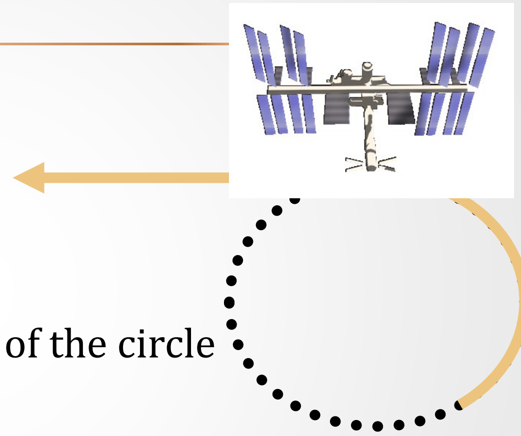
$$\frac{\Delta v}{\Delta t} = \frac{v^2}{r}$$

$$a_C = \frac{v^2}{r} = r\omega^2$$



02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- At any given moment
  - $\boldsymbol{v}$ is pointing tangent to the circle
  - $\boldsymbol{a_c}$ is pointing towards the center of the circle



- If the object suddenly broke from circular motion would travel in line tangent to circle

Have a string with something soft on end.
Swing it and let go to illustrate.

02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Two identical cars are going around two corners at 30 m/s. Each car can handle up to 1 g. The radius of the first curve is 50 m and the radius of the second is 100 m. Do either of the cars make the curve? (hint find the a_c)

$$a_{c1} = \frac{v^2}{r} \rightarrow a_{c1} = \frac{\left(30\ \frac{m}{s}\right)^2}{50\ m} \rightarrow a_{c1} = 18\ \frac{m}{s^2}$$

Can’t make it

$$a_{c2} = \frac{\left(30\ \frac{m}{s}\right)^2}{100\ m} = 9\ \frac{m}{s^2}$$

Yes

02-06 ANGULAR VELOCITY AND CENTRIPETAL ACCELERATION

- Rotating too fast can make you sick, but these problems won't.

- Read 6.3

02-07 CENTRIPETAL FORCE AND BANKED CURVES

In this lesson you will…

- Calculate coefficient of friction on a car tire.
- Calculate ideal speed and angle of a car on a turn.

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- Do the lab on your worksheet

- Are force and mass a direct or inverse relation?
- Are force and speed a direct or inverse relation?
- Are force and radius a direct or inverse relation?
- A car will skid when the centripetal force required to make it turn is greater than the force of friction. What are two things the driver could do to lessen the change of a skid in a curve?

Direct
Direct
Inverse

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

Lower speed or bigger radius. Lowering mass will decrease friction, so overall changing mass will not affect the car’s cornering.

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- Newton's 2nd Law
  - Whenever there is acceleration there is a force to cause it

- $F = ma$
- $F_C = ma_C$

$$F_C = \frac{mv^2}{r} = mr\omega^2$$

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- Centripetal Force is not a new, separate force created by nature!
- Some other force creates centripetal force
  - Swinging something from a string → tension
  - Satellite in orbit → gravity
  - Car going around curve → friction

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- A 1.25-kg toy airplane is attached to a string and swung in a circle with radius = 0.50 m. What was the centripetal force for a speed of 20 m/s? What provides the F_c?

- F_c = 1000 N
- Tension in the string

$$F_C = \frac{mv^2}{r}$$
$$= \frac{(1.25\ kg)\left(20\frac{m}{s}\right)^2}{0.50\ m}$$
$$= 1000\ N$$

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- What affects F_c more: a change in mass, a change in radius, or a change in speed?

- A change in speed since it is squared and the others aren't.

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- When a car travels around an unbanked curve, static friction provides the centripetal force.

- By banking a curve, this reliance on friction can be eliminated for a given speed.

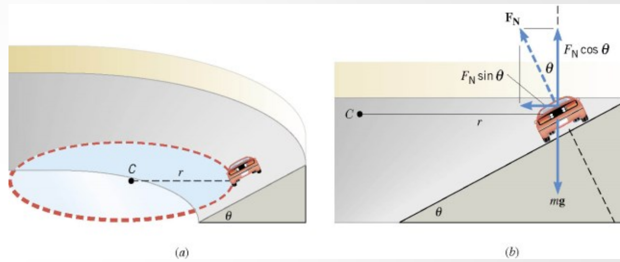
02-07 CENTRIPETAL FORCE AND BANKED CURVES

- A car travels around a friction free banked curve
- Normal Force is perpendicular to road
  - x component (towards center of circle) gives centripetal force

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

  - y component (up) cancels the weight of the car

$$F_N \cos\theta = mg$$



02-07 CENTRIPETAL FORCE AND BANKED CURVES

- Divide the *x* by the *y*

$$\frac{F_N \sin\theta = \frac{mv^2}{r}}{F_N \cos\theta = mg}$$

- Gives

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

- Notice mass is not involved

Ask what happens when go to fast? (slide up and over top of curve)
Ask what happens when go to slow? (slide down curve)

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- In the Daytona International Speedway, the corner is banked at 31° and *r* = 316 m. What is the speed that this corner was designed for?

- *v* = 43 m/s = 96 mph
- Cars go 195 mph around the curve. How?
- Friction provides the rest of the centripetal force

$$\tan\theta = \frac{v^2}{rg} \rightarrow \tan 31° = \frac{v^2}{(316\ m)\left(9.8\frac{m}{s^2}\right)}$$

$$.6009(316\ m)\left(9.8\frac{m}{s^2}\right) = v^2$$

$$1861\ \left(\frac{m}{s}\right)^2 = v^2$$

$$v = 43\ m/s$$

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- Why do objects seem to fly away from circular motion?
- They really go in a straight line according to Newton's First Law.

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- How does the spin cycle in a washing machine work?

- The drum's normal forces makes the clothes to travel in a circle. The water can go through the holes, so it goes in a straight line. The water is not spun out, the clothes are moved away from the water.

02-07 CENTRIPETAL FORCE AND BANKED CURVES

Remember the good old days when cars were big, the seats were vinyl bench seats, and there were no seat belts? Well when a guy would take a girl out on a date and he wanted to get cozy, he would put his arm on the back of the seat then make a right hand turn. The car and the guy would turn since the tires and steering wheel provided the centripetal force. The friction between the seat and the girl was not enough, so the girl would continue in a straight path while the car turned underneath her. She would end up in the guy's arms.

02-07 CENTRIPETAL FORCE AND BANKED CURVES

- There is a real force to make you do these problems.

- Read 6.5

02-08 SATELLITES AND KEPLER'S LAWS

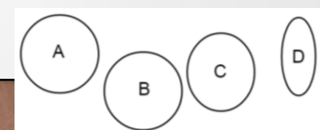
In this lesson you will…

- Explain Earth's gravitational force.
- Describe the gravitational effect of the Moon on Earth.
- Discuss weightlessness in space.
- State Kepler's laws of planetary motion.

02-08 SATELLITES AND KEPLER'S LAWS

- Do the lab on your worksheet

- What effect did moving the pins have on the eccentricity?
- The earth's orbit eccentricity is about 0.0167. One of these ellipses has an eccentricity of 0.0167. Which is it?
- Does the ovalness of the earth's orbit cause the seasons as based on the shape of the earth's orbit from this lab?



Farther apart = more eccentric
B
No

02-08 SATELLITES AND KEPLER'S LAWS

- Satellites
  - Any object orbiting another object only under the influence of gravity
  - Gravity provides the centripetal force
  - There is only one speed that a satellite can have if the satellite is to remain in an orbit with a fixed radius.

02-08 SATELLITES AND KEPLER'S LAWS

- Why only one speed?
- $F_c = \frac{mv^2}{r}$ $F_g = \frac{GMm}{r^2}$
- $\frac{mv^2}{r} = \frac{GMm}{r^2}$

$$v = \sqrt{\frac{GM}{r}}$$

  - r is measured from the center of the earth

02-08 SATELLITES AND KEPLER'S LAWS

$$v = \sqrt{\frac{GM}{r}}$$

- Since $1/r$
  - As r decreases, v increases
- Mass of the satellite is not in the equation, so speed of a massive satellite = the speed of a tiny satellite

02-08 SATELLITES AND KEPLER'S LAWS

- Calculate the speed of a satellite 500 km above the earth's surface.

$$r = 500000\ m + 6.38 \times 10^6\ m = 6.88 \times 10^6\ m$$

$$G = 6.67 \times 10^{-11}\ \frac{Nm^2}{kg^2}$$

$$M = 5.98 \times 10^{24}\ kg$$

$$v = \sqrt{\frac{GM}{r}}$$

$$v = \sqrt{\frac{\left(6.67 \times 10^{-11}\ \frac{Nm^2}{kg^2}\right)(5.98 \times 10^{24}\ kg)}{6.88 \times 10^6\ m}} = 7614\ m/s$$

02-08 SATELLITES AND KEPLER'S LAWS

- Find the mass of a black hole where the matter orbiting it at $r = 2.0 \times 10^{20}$ m move at speed of 7,520,000 m/s.

$$v = \sqrt{\frac{GM}{r}}$$

$$7520000\ \frac{m}{s} = \sqrt{\frac{\left(6.67 \times \frac{10^{-11} Nm^2}{kg^2}\right) M}{2.0 \times 10^{20}\ m}}$$

$$5.655 \times 10^{13}\,\frac{m^2}{s^2} = \frac{\left(6.67 \times 10^{-11}\,\frac{Nm^2}{kg^2}\right) M}{2.0 \times 10^{20}\ m}$$

$$1.131 \times 10^{34}\,\frac{m^3}{s^2} = \left(6.67 \times 10^{-11}\,\frac{Nm^2}{kg^2}\right) M$$

$$M = 1.70 \times 10^{44}\ kg$$

02-08 SATELLITES AND KEPLER'S LAWS

- Astronauts in the space shuttles and international space station seem to float
- They appear weightless
- They are really falling
  - Acceleration is about g towards earth

02-08 SATELLITES AND KEPLER'S LAWS

… they were finally able to close and repressurize the hatch. Several months later a new team of cosmonauts returned and found the hatch impossible to permanently repair. Instead they attached a set of clamps to secure it in place.

It is this set of clamps that Linenger and Tsibliyev are staring at uneasily seven years later. To his relief, the commander opens the hatch Without incident and crawls outside onto an adjoining ladder just after nine o'clock. Linenger begins to follow. Outside the Sun is rising. The Russians have planned the EVA at a sunrise so as to get the longest period of light. But because of that, Linenger's first view of space is straight into the blazing Sun. "The first view I got was just blinding rays coming at me," Linenger told his postflight debriefing session. "Even with my gold visor down, it was just blinding. [I] was basically unable to see for the first three or four minutes going out the hatch."

From *Dragonfly: NASA and the Crisis Aboard Mir* by Bryan Burrough

02-08 SATELLITES AND KEPLER'S LAWS

The situation only gets worse once his eyes clear. Exiting the airlock, Linenger climbs out onto a horizontal ladder that stretches out along the side of the module into the darkness. Glancing about, trying in vain to get his bearings, he is suddenly hit by an overwhelming sense that he is falling, as if from a cliff. Clamping his tethers onto the handrail, he fights back a wave of panic and tightens his grip on the ladder. But he still can't shake the feeling that he is plummeting through space at eighteen thousand miles an hour. His mind races.

You're okay. You're okay. You're not going to fall. The bottom is way far away.

From *Dragonfly: NASA and the Crisis Aboard Mir* by Bryan Burrough

02-08 SATELLITES AND KEPLER'S LAWS

And now a second, even more intense feeling washes over him: He's not just plunging off a cliff. The entire cliff is crumbling away. "It wasn't just me falling, but everything was falling, which gave [me] even a more unsettling feeling," Linenger told his debriefers. "So, it was like you had to overcome forty years or whatever of life experiences that [you] don't let go when everything falls. It was a very strong, almost overwhelming sensation that you just had to control. And I was able to control it, and I was glad I was able to control it. But I could see where it could have put me over the edge."

From *Dragonfly: NASA and the Crisis Aboard Mir* by Bryan Burrough

02-08 SATELLITES AND KEPLER'S LAWS

The disorientation is paralyzing. There is no up, no down, no side. There is only three-dimensional space. It is an entirely different sensation from spacewalking on the shuttle, where the astronauts are surrounded on three sides by a cargo bay. And it feels nothing—*nothing*—like the Star City pool. Linenger is an ant on the side of a falling apple, hurtling through space at eighteen thousand miles an hour, acutely aware what will happen if his Russian-made tethers break. As he clings to the thin railing, he tries not to think about the handrail on Kvant that came apart during a cosmonaut's spacewalk in the early days of Mir. Loose bolts, the Russians said.

Loose bolts.

From *Dragonfly: NASA and the Crisis Aboard Mir* by Bryan Burrough

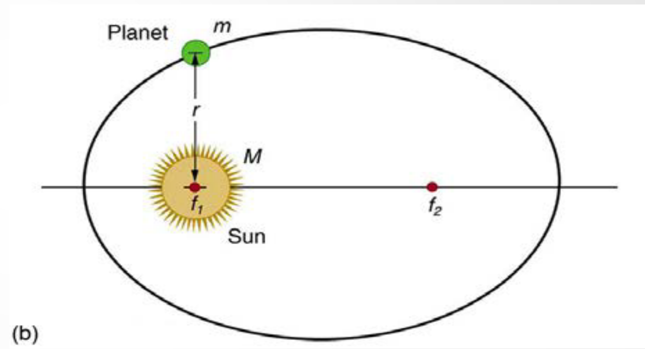
02-08 SATELLITES AND KEPLER'S LAWS

- After studying motion of planets, Kepler came up with his laws of planetary motion
- Newton then proved them all using his Universal Law of Gravitation
- Assumptions:
  - A small mass, *m*, orbits much larger mass, *M*, so we can use *M* as an approximate inertia reference frame
  - The system is isolated

02-08 SATELLITES AND KEPLER'S LAWS

1. The orbit of each planet about the Sun is an ellipse with the sun at one focus.

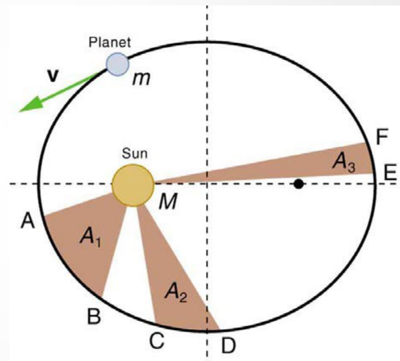
Watch video Kepler's First Law



02-08 SATELLITES AND KEPLER'S LAWS

2. Each planet moves so that an imaginary line drawn from the sun to the planet sweeps out equal areas in equal times.

Watch video Kepler's Second Law



02-08 SATELLITES AND KEPLER'S LAWS

3. The ratio of the squares of the periods of any two planets about the sun is equal to the ratio of the cubes of their average distances from the sun.

$$\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$$

- These laws work for all satellites
- For circular orbits

$$T^2 = \frac{4\pi^2}{GM} r^3 \rightarrow \frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

- Table 6.2 gives data about the planets and moons

T is period and r is average orbital radius

02-08 SATELLITES AND KEPLER'S LAWS

- Use the data of Mars in Table 6.2 to find the mass of sun.
  Mars, $r = 2.279 \times 10^8$ km, $T = 1.881$ y

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

$$r = 2.279 \times 10^8\ km = 2.279 \times 10^{11}\ m, T = 1.881\ y = 59359845.6\ s$$

$$\frac{(59359845.6\ s)^2}{(2.279 \times 10^{11}\ m)^3} = \frac{4\pi^2}{\left(6.673 \times 10^{-11} \frac{Nm^2}{kg^2}\right) M}$$

$$235129.2 \frac{m^3}{kg}\ M = 4.6730 \times 10^{35}\ m^3$$

$$M = 1.99 \times 10^{30}\ kg$$

02-08 SATELLITES AND KEPLER'S LAWS

- Draw an ellipse around your answers to these homework problems