Newton's Laws of Motion Momentum and Energy

Chapter 2-3

Second Law of Motion

- "The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object."
- Means "acceleration" ~ $\frac{\text{Force}}{\text{mass}}$

Acceleration

Force **causes** acceleration

Force over mass

$$a = \frac{F}{m}$$

Solve for the force:

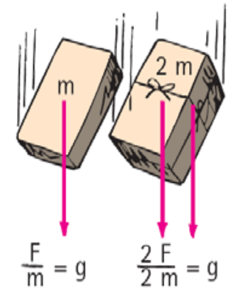
$$F = ma$$

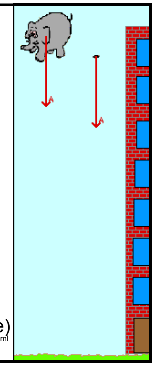
Freely falling objects

- Acceleration of gravity is 9.81 $\frac{m}{s^2}$
- Use g, a constant
  - 9.81 $\frac{m}{s^2}$
  - For lecture calculations round to 10 $\frac{m}{s^2}$

$$a = \frac{F}{m}$$

$$g = \frac{F}{m}$$





(Neglect air resistance in this example)

- http://www.physicsclassroom.com/mmedia/newtlaws/efff.html

Weight is a Force

$$g = \frac{F}{m} \rightarrow Weight = mg$$

Weight is a Force

- Function of g (acceleration of gravity)
- Proper units:
  - Gravity $\frac{m}{s^2}$
  - Mass kg
  - Force kg $\bullet \frac{m}{s^2}$
- Different planet—different weight for the same mass

$$g = \frac{F}{m}$$

$$mg = F$$

Freely falling objects

- Boulder vs. feather

$$a = \frac{F}{m} \qquad a = \frac{F}{m}$$

- Boulder has more inertia, but not more acceleration—so how come it falls faster?

Galileo's investigation of motion

- Surface area changes air resistance
- Objects reach terminal velocity due to air resistance
- In vacuum, this is not a factor

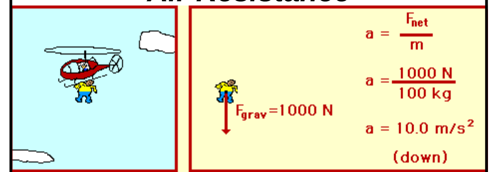
Air Resistance

- Acceleration is less than g due to air resistance
- Friction of air against falling object
- Air resistance depends on
  - Speed
  - Frontal area exposed to air

Air Resistance

- Falling object has constant mass, constant weight
- Terminal velocity reached when air resistance matches weight
- Air resistance function of speed and area
- Falling object has variable frontal area if you deploy a parachute

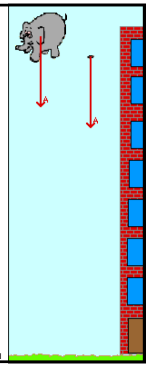
Air Resistance



- Parachute increases frontal area, increases air resistance
- Increased air resistance balanced with slower speed

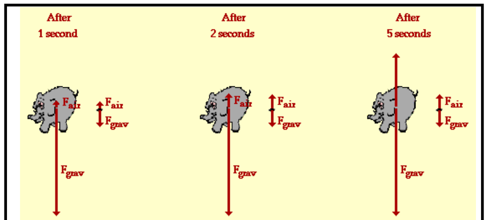
- http://www.physicsclassroom.com/mmedia/newtlaws/sd.html

Air Resistance



- Greater air resistance for elephant, because it is larger
- Greater weight because it is more massive
- More speed required to gain air resistance to overcome the greater weight

- http://www.physicsclassroom.com/mmedia/newtlaws/efar.html



- Force of air resistance balances greater mass at greater speed
- Heavier skydiver has greater terminal velocity than lightweight skydiver

- http://www.physicsclassroom.com/mmedia/newtlaws/efar.html

Zero Acceleration

- One case: Motionless objects
  (no change in velocity)
- Downward force created by gravity
- Upward force created by surface

Zero Acceleration

- Another case: Cart crossing room at constant velocity (no change in velocity)
- Net force is zero
- Force applied
  pushing force = frictional force

Zero Acceleration

- Push down on spring
- Spring pushes up on you
- Each molecule of table acts like microscopic spring pushing up on object

Friction

- Works against forces
- Opposite direction
- Not dependent on speed
- Not dependent on area of contact
- Only dependent on weight

Third Law of Motion

- "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first."
- Force is an interaction between objects
- Action—reaction pairs

Force interaction

$$\frac{F}{m} = a \qquad \frac{F}{m} = a \qquad \frac{F}{m} = a$$

- Forces in action-reaction pair are equal
- Different masses must have different accelerations

Action—reaction pairs

- Force on object moves it
- Force by object acts on other things
- Always equal

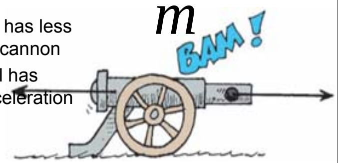
Action—reaction pair

- Hammer exerts force on nail
- Nail exerts equal force on hammer

Action—reaction pairs

- Consider firing a cannon
- Force on cannonball and on cannon the same
- cannonball has less mass than cannon
- Cannonball has greater acceleration

$$\frac{F}{m} = a \qquad \frac{F}{m} = a$$



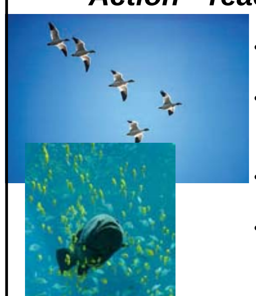
Action—reaction pairs

- Rifle has less acceleration than the bullet
- Because it has greater mass
- Forces are the same

Action—reaction pairs

- Rocket accelerates upward
- Recoil from exhaust gas

Action—reaction pairs

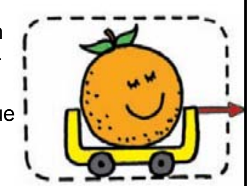


- Birds push down on air
- Air pushes up on bird
- Fish pushes backward on water
- Water pushes forward on fish

- http://en.wikipedia.org/wiki/Fish

Action—reaction pairs

- Forces of atoms within objects are in action—reaction pairs
- No net acceleration due to these molecular forces
- External force needed to move object



Bug vs. Bus

- If a bug is splatted against the windshield of a bus on the freeway, is the force the bug exerts on the bus the same as the force the bus exerts on the bug?
- Justify why the deceleration of the bug is not the same as the deceleration of the bus with Newton's third law.

Summary of laws of motion

Newton's First Law of Motion

- Object at rest tends to remain at rest
- Objects in motion tend to remain moving
  - Law of Inertia
  - Function of mass of object
- Changes in motion occur due to presence of net force acting on object

Summary of laws of motion

Newton's Second Law of Motion

- Acceleration proportional to net force

$$a \approx \frac{F}{m}$$

Summary of laws of motion

Newton's Third Law of Motion

- Objects exert equal and opposite forces upon one another
- Action—reaction pairs have no net force

Momentum

- Momentum is inertia in motion
- **Mass x velocity**
- Has both magnitude and direction
- Large mass or high speed can give object great amount of momentum

Momentum = m•v

- Change momentum by
  - changing mass
  - or velocity—usually velocity
- What causes changes in velocity?
- Force
- Time is also important

Momentum and Impulse

- Apply force over time to change velocity and momentum
- Greater time of application, greater change in momentum
- Force x time interval is IMPULSE

Impulse = F•t

- Force x time interval
- Impulse changes momentum
- Technically: $Ft = \Delta(mv)$
- Realistically: $Ft = m\Delta v$

Impulse Increasing Momentum

$$Ft = m\Delta v$$

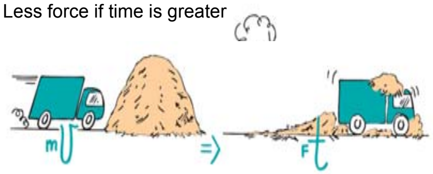
- Pushing a child on a swing—the force
- Increases momentum
- Longer push increases momentum more than a short one

- http://www.bcm.edu/oto/research/cochlea/Volta/16.html

Impulse Decreasing Momentum

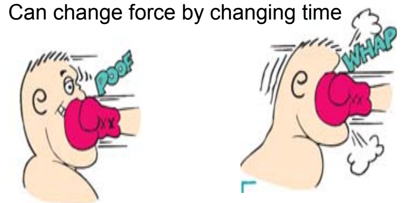
- Stopping the out of control car
- Change momentum to zero
- Less force if time is greater

$$Ft = m\Delta v$$



Impulse Changes Momentum

- Can change force by changing time



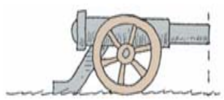
- Move away increases time, reduces force
- Toward decreases time, increases force

Bounce increases impulse

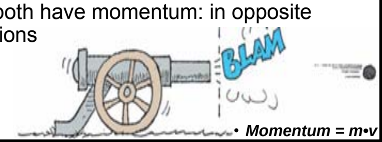
- There is a change in velocity direction, making a greater Δv
- So greater force is required
- Water changes direction, has greater impulse than a flat paddle

$$Ft = m\Delta v$$

Conservation of Momentum



- The system: the cannon and the ball
- When it fires, momentum is conserved—they both have momentum: in opposite directions



- ***Momentum = m•v***

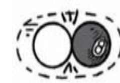
Conservation of Momentum

- No net force
- No net momentum

- ***Momentum = m•v***

Conservation of Momentum

- In the absence of external force, the momentum of the system remains unchanged



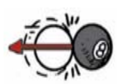
- ***Momentum = m•v***

- Consider individual balls as individual systems: momentum of each does change

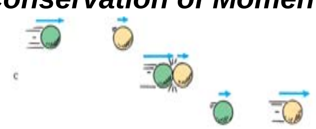
Conservation of Momentum

- Net momentum is the same before the collision
- As after the collision

- ***Momentum = m•v***



Conservation of Momentum



a. Yellow ball starts stationary
b. Both balls moving opposite directions
c. Green ball moving faster

- ***Momentum = m•v***

Work

Transference of Energy

Work = Force x distance

W=Fd

Work   W=Fd

- Nothing about time in definition
- Slow or fast
- Same force, same distance = same work

Work

- Lifting load against the force of the weight of the object
- Twice the distance results in twice the work
- Twice the weight is twice the work

Work   W=Fd

- Twice the weight
- Twice the distance

Work   W=Fd

- Units of work are Joules
- Work is energy

Work   W=Fd

Units of force : Newtons = $\frac{kg \cdot m}{s^2}$

Force x distance : Newton meters

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

=Joules

Work   W=Fd

- Weight lifter does work to lift barbell
- expends energy to keep the potential energy in the barbell
- But he does no work on the barbell after it is lifted