## From last time

***Gravity and centripetal acceleration***

$a_c = \frac{v^2}{r} \; m/s^2$ $\quad$ $F = 6.7 \times 10^{-11} \frac{m_1 \times m_2}{r^2}$

Used to explore interesting questions like what is at the center of the galaxy

HW#2: Due

HW#3: Chapter 5: Conceptual: # 22 Problems: # 2, 4

Chapter 6: Conceptual: # 18 Problems: # 2, 5

Exam 1: Next Wednesday, Review Monday,

Scantron with XX questions, bring #2 pencil

Chapters 1 and 3-6

1 Page, front only, equation sheet allowed

## What is the central mass?

- One star swings by the hole at a minimum distance b of 17 light hours (120 A.U. or close to three times the distance to Pluto) at speed v=5000 km/s, period 15 years.

$a_c = \frac{v^2}{r} = 6.7 \times 10^{-11} \frac{m}{r^2}$

$m = \frac{rv^2}{6.7 \times 10^{-11}} = \frac{1.8 \times 10^{13} \bullet 25 \times 10^{12}}{6.7 \times 10^{-11}} = 6.7 \times 10^{36}$

- Mass Sun: $2 \times 10^{30}$, 3.4million solar mass black hole(approximate estimate) at the center of our Milky Way galaxy!



## Discussion so far…

- So far we have talked about
  - Velocity and Acceleration
  - Momentum and conservation of momentum
  - Momentum transfer changing the velocity of an object
  - That momentum transfer resulting from a force when the objects are in contact
  - Newton's relation: Acceleration = Force / mass



## Something missing

- With these tools, can think about the world in many ways.
  - Collisions resulting in a momentum transfer
  - Gravitational forces resulting in acceleration of falling bodies and orbits of planets.
- But this leaves something out
- Think about firing a rifle:
  - Before pulling the trigger, both rifle and bullet are stationary: total momentum is zero.
  - After firing, the bullet and rifle move in opposite directions. Total momentum is *still* zero.
  - But clearly the situation before and after is different.



## Energy

- Both objects moving in final state.
- That movement represents energy.
- In addition to momentum, the energy is physical property of the system.
- We will see that it is also conserved.
- In the rifle - bullet example
  - Before firing, the energy is stored in the gunpowder.
  - After firing, most of the energy appears as the motion of the bullet and rifle
  - Some of the energy appears as heat.



## Before Energy Consider Work

- Work is done whenever a body is continually pushed or pulled through a distance.
- Twice as much work is done when the body is moved twice as far.
- Pushing twice as hard over the same distance does twice as much work.
- Work = Force x Distance

## Work, cont.

- Force has units of Newtons (N)
  Distance has units of meters (m)
  So work has units of N-m, defined as Joules (J).
- *Example*:
  The Earth does work on an apple when the apple falls.
  *The force applied is the force of gravity*
- *Example*:
  I do work on a box when I push it along the floor.
  *The force applied is from my muscles*



## Multi-part question

I lift a body weighing 1 N upward at a constant vertical velocity of 0.1 m/s. The Net force on the body is

A. 1 N upward
B. 1 N down
C. 0 N

Since the acceleration is zero, the net force must be zero.



## Question, cont.

The force I exert on the body is

A. 1 N up
B. 1 N down
C. 0

Since *net* force is zero, and the gravitational force is 1 N down, I must be exerting 1 N up.



## Question, cont.

After lifting the 1 N body a total distance of 1 m, the work I have done on the body is

A. 1 J
B. 0.1 J
C. 0 J

Work = Force x Distance
= 1 N x 1 m = 1 N-m = 1 Joule



## Question, cont.

After lifting the 1 N body a total distance of 1 m, the Net work done on the body is

A. 1 J
B. 0.1 J
C. 0 J

Work = $\text{Force}_{\text{Net}}$ x Distance
= (1 N - 1 N) x 1 m = 0 Joule



## Energy

A object's energy is the **amount of work it can do**.
Energy comes in many forms

- **Kinetic Energy**
- **Gravitational Energy**
- **Electrical Energy**
- **Thermal Energy**
- **Solar Energy**
- **Chemical Energy**
- **Nuclear Energy**

It can be converted into other forms without loss (*i.e* it is conserved)

## Energy of motion

In outer space, I apply a force of 1 N to a 1 kg rock for a distance of 1 m.

I have done *Force* x *Distance* = (1 N)x(1 m) = 1 J of work.

After applying the force for 1 m, the rock is moving at some final velocity $v_{final}$ as a result of the acceleration *Force/mass.*

So the energy I expended in doing work has caused the body to change its velocity from zero to $v_{final}$.



## Kinetic energy (energy of motion)

- Work = Force x Distance
- A constant applied force leads to an acceleration.
- After the distance is moved, the body is traveling at some final velocity $v_{final}$.
- So the result of the work done is to change the body's velocity from zero to $v_{final}$



## Work-energy relation

- The acceleration of the body is related to the net force by *F=ma*

$$Work = F_{net} \times d = (ma) \times d = m \times (ad)$$

*For a body initially at rest, constant accel. says*

$$\left\{ \begin{aligned} & d = \frac{1}{2}at^2, \ so \ \ t = \sqrt{\frac{2d}{a}} \\ & v_{final} = at = a\sqrt{\frac{2d}{a}} = \sqrt{2ad} \\ & ad = \frac{1}{2}v_{final}^2 \end{aligned} \right\}$$

$$Work = F_{net} \times d = \frac{1}{2}mv_{final}^2$$

$\frac{1}{2}mv^2$ is called Kinetic Energy, or energy of motion



## Work-energy relation

- The kinetic energy of a body is $\frac{1}{2}mv^2$
- The kinetic energy will change by an amount equal to the **net work** done on the body.



## A more general form

- If the object initially moving at some velocity $v_{initial}$ it has kinetic energy $\frac{1}{2}mv_{initial}^2$
- As the result of a net work $W_{net}$, the velocity increases to $v_{final}$, $\frac{1}{2}mv_{final}^2$
- and the Kinetic Energy increases to $W_{net} = \frac{1}{2}mv_{final}^2 - \frac{1}{2}mv_{initial}^2$

*The change in kinetic energy is equal to the net work done.*



## Gravitational energy

- An object in a gravitational field can do work when it falls.
- We might say that energy is stored in the system.

## Ball falls down in gravity

- Ball initially held at rest.
  - $v_{initial}=0$
  - Kinetic energy = 0
- Ball released.
- Gravitational force = *mg*, falls with acceleration *g*
- Work done by gravitational force in falling distance *h* is *Force* x *Distance* = *mgh*.
- Ball final kinetic energy = *mgh* = $\frac{1}{2}mv_{final}^2$



## Ball moved up in gravity

- Work done by me on ball
  - Ball initially held at rest by me.
  - I move the ball slowly upward a distance *h*.
  - Force applied by me is *mg* upward.
  - Work done by me on ball is *Force* x *Distance* = *mgh*
- Work done by gravity on ball
  - *Force* x *Distance* = *-mgh*
- Net (total) work done on ball = *mgh-mgh* = 0
- Consistent with zero change in kinetic energy of ball during this time (I.e. ending velocity is same as starting velocity).



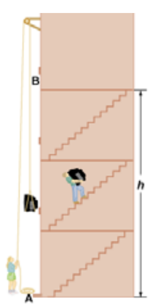
## Work Done by Gravity

- Change in gravitational energy,

  Change in energy = *mgh*

  true for any path : *h*, is simply the height difference, $y_{final} - y_{initial}$

- A falling object converts gravitational potential energy to its kinetic energy
- Work needs to be done on an object to move it vertically up - work done is the same no matter what path is taken






## Electrical Energy

- Electricity is the flow of charged particles.
- Charged particles have an electromagnetic force between them similar to the gravitational force.
- This force can do work.
- Doing work against this force can store energy in the system.
- The energy can be removed at any time to do work.



## Thermal Energy

- Otherwise known as heat.
- The temperature of an object is related to the amount of energy stored in the object.
- The energy is stored by the microscopic vibratory motion of atoms in the material.
- This energy can be transferred from one object to another by contact.
- It can also be turned into work by contact.



## Storing energy

- Energy is neither created nor destroyed, but is just moved around.
- Or more accurately, it changes form.
- I do work by lifting a body against gravity.
- If the body now drops, it can do work when it hits (pounding in a nail, for instance).

Could say that the work I did lifting the body is stored until the body hits the nail and pounds it in.

Potential Energy