Week 12

Friction and Collisions

Topics for this week

1. Displacement of friction
2. Modelling collisions

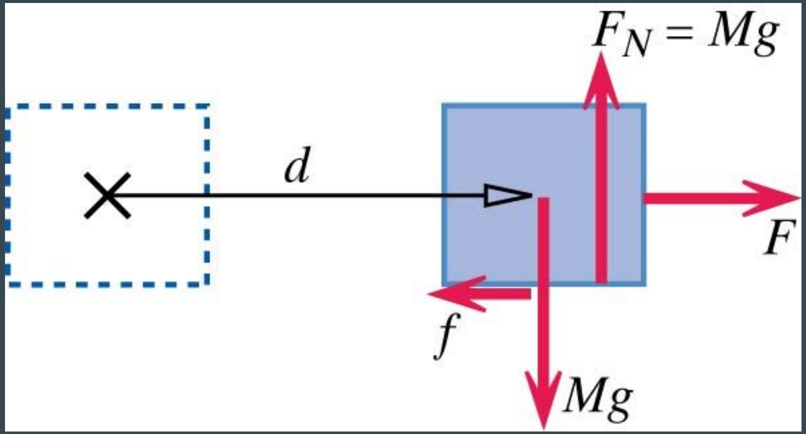
By the end of the week

1. Be able to make energy predictions involving friction
2. Analyze the collision of two neutron stars

Clicker Question 3

A block of mass M is pulled at constant speed with force F a distance d across a surface. Using the energy principle, what can you say about the change in thermal energy of the block?

A. $\Delta E_{thermal} > 0$
B. $\Delta E_{thermal} = 0$
C. $\Delta E_{thermal} < 0$

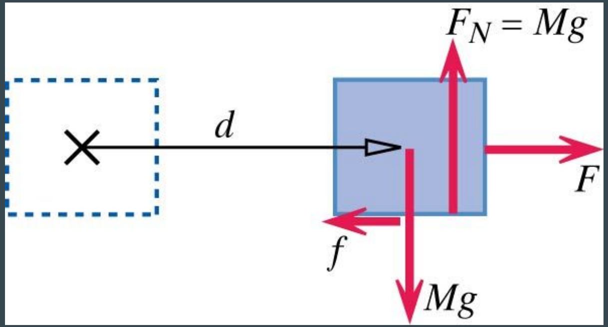


Clicker Question 3 - Solution

- Apply the energy principle to the center of mass system (point particle)

$$\Delta K_{trans} = (F - f)d$$

- Apply the energy principle to the extended system (real system)

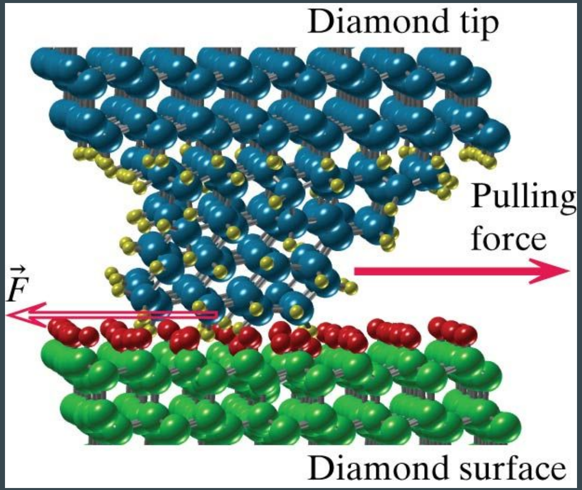


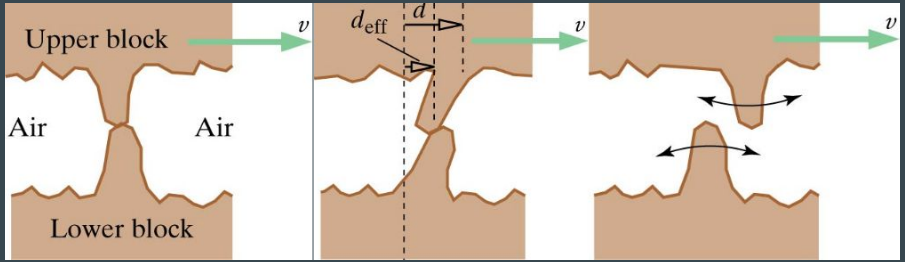
$$\Delta K_{trans} + \Delta E_{therm} = (F - f)d$$

$$\Delta E_{therm} = 0$$

Displacement of friction forces

- From observation, we know that the thermal energy increases
  - It must be that the applied force and the friction force do not move through the same displacement!
- At the atomic level surfaces are not flat but irregular
  - As few as three asperities make contact
  - The very high loads at these contact regions result in adhesion and deformation
    - The contact force displacement is different from the system
  - Vibration of the asperities results in an increase in thermal energy for the system





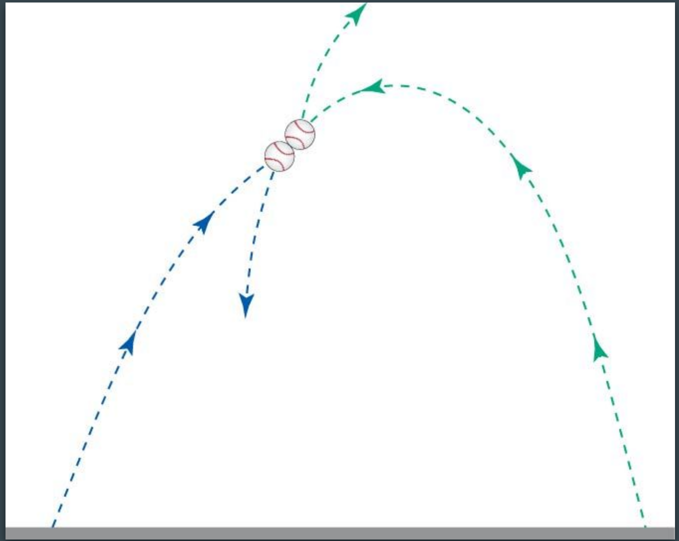
Collisions

Collisions

- An interaction between two objects that takes place in a short amount of time
  - The interaction between the two objects is much larger than other interactions with the surroundings
  - The objects do not have to make physical contact
  - Valid at all length scales

$$\Delta\vec{p}_{system} = 0$$

$$\Delta E_{system} = 0$$



Example: A bounced ball

A ball whose mass is 0.1 kg falls and hits the floor with a speed of 6 m/s, then rebounds upward with a speed of 5 m/s. If the ball was in contact with the floor for approximately 12×10^{-3} seconds, how much larger is the collision force compared to the gravitational force?

Example: A bounced ball - Solution

- Use the momentum principle to estimate the collision force

$$\Delta\vec{p}_{ball} = \vec{F}_{net}\Delta t$$

$$m(\vec{v}_f - \vec{v}_i) = (F_{contact} - mg)\hat{y}\Delta t$$

$$\frac{m(\vec{v}_f - \vec{v}_i)}{\Delta t} + mg\hat{y} = \vec{F}_{contact}$$

$$|\vec{F}_{contact}| \approx 100|\vec{F}_{grav}|$$

Classifying collisions

- By convention we classify collisions based on the change of internal energy for the system of colliding objects
  - Elastic Collision: No change in internal energy for the system
    - The system doesn’t change shape, temperature, etc.
    - This is an idealization for macroscopic collisions due to dissipation

$$\Delta K = 0$$

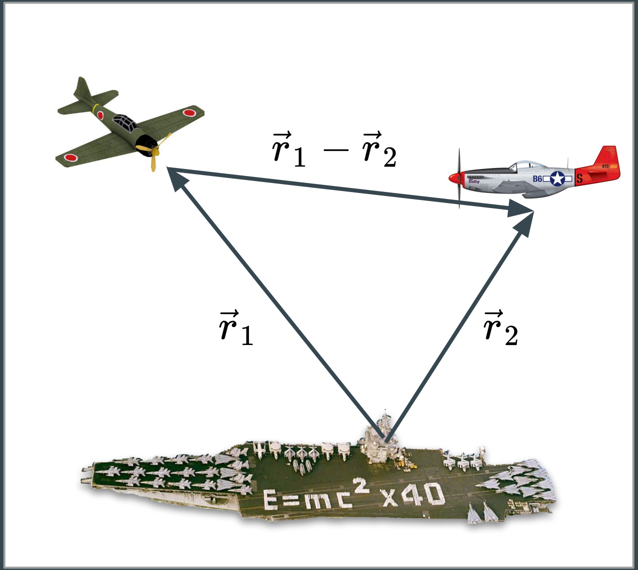
  - Inelastic Collision: There is some change in internal energy for the system
    - The system changes shape, temperature, etc.
    - Maximally Inelastic Collisions are when the colliding objects stick together
    - http://www.youtube.com/watch?v=QfDoQwIAaXg
- In all types of collisions, momentum and total energy are conserved during the collision of the two objects

Changing the reference frame

- A frame of reference is a perspective from which a system is observed
  - Collision problem can often be simplified by changing to a moving (inertial) frame of reference
    - An inertial frame is one that is not accelerating
    - Sometimes the center of mass
- Consider tracking the position of two planes about to collide from a stationary ship
  - The ship measures the velocity of each plane v_1 and v_2
  - The velocity of plane 1 as measured by plane 2:

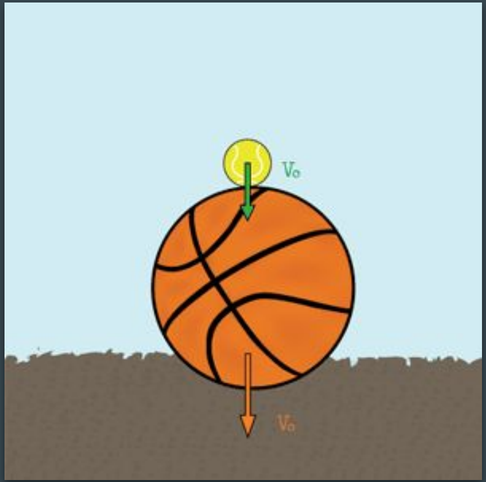
$$\vec{v}_1' = \vec{v}_1 - \vec{v}_2$$

$$\vec{v}' = \vec{v}_{stationary} - \vec{v}_{moving}$$



Example: Super Bounce

A tennis ball of mass m perched on top of a basketball of mass M falls from rest towards the Earth from a height h. The basketball & tennis ball collide with the ground in an elastic collision. The basketball mass is much larger than the tennis ball. How high does the tennis ball bounce?

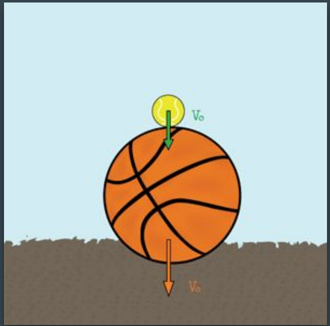


Example: Super Bounce Soln.

- How fast are the balls moving when they reach the ground?
  - Both balls and the Earth in the system with energy conservation

$$\Delta K_{trans} + \Delta U_{grav} = 0$$

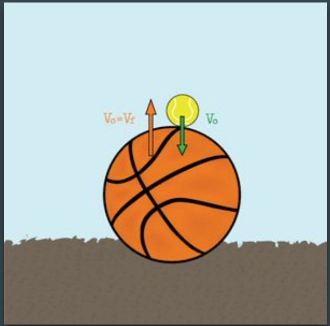
$$\vec{v}_0 = -\sqrt{2gh}\hat{y}$$



- The tennis ball collides with the Earth first
  - The Earth is much larger and doesn't move
  - The collision happens so fast the tennis ball is still moving down

$$\vec{v}_{basketball} = \sqrt{2gh}\hat{y}$$

$$\vec{v}_{tennis} = -\sqrt{2gh}\hat{y}$$



Example: Super Bounce Soln.

- The tennis ball collides with the basketball
  - What would a small bug riding on the basketball predict?
    - Before the collision

$$\vec{v}' = \vec{v}_{stationary} - \vec{v}_{moving}$$

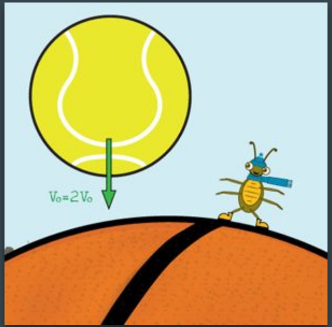
$$\vec{v}' = \vec{v}_{tennis} - \vec{v}_{basketball}$$

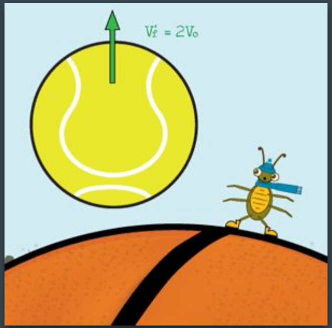
$$\vec{v}' = -\sqrt{2gh}\hat{y} - \sqrt{2gh}\hat{y}$$

$$\vec{v}' = -2\sqrt{2gh}\hat{y}$$

    - After the collision

$$\vec{v}'_f = 2\sqrt{2gh}\hat{y}$$





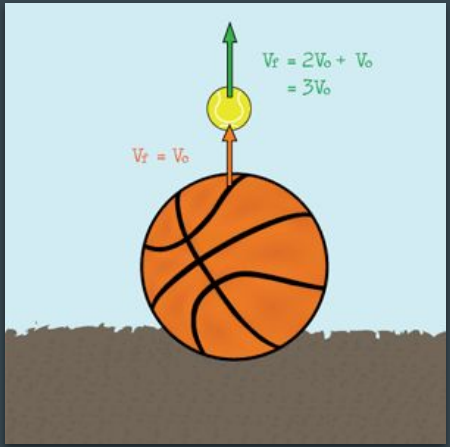
Example: Super Bounce Soln.

- Determine how fast the tennis ball is moving with respect to the stationary frame (the Earth)

$$\vec{v}_{stationary} = \vec{v}' + \vec{v}_{moving}$$

$$\vec{v}_{tennis,f} = 2\sqrt{2gh}\hat{y} + \sqrt{2gh}\hat{y}$$

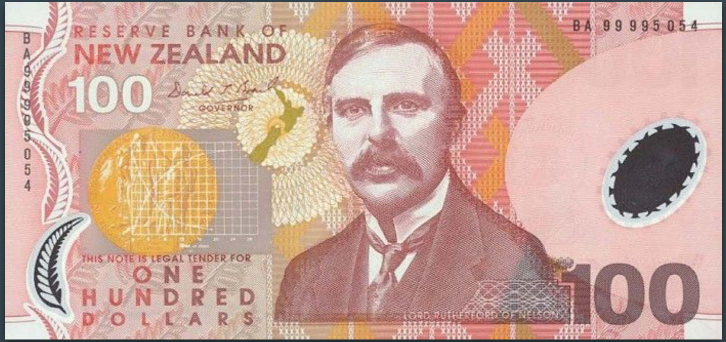
$$\vec{v}_{tennis,f} = \sqrt{18gh}\hat{y}$$



- How high does this ball go?
    - Using energy conservation again
    - Final height is 9 times the drop height!
    - What happens if we have three stacked balls?

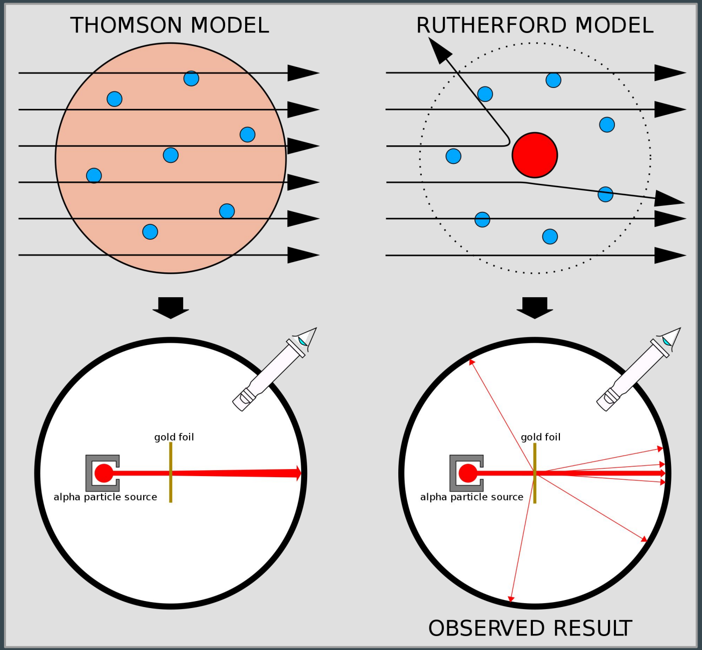
The Plum Pudding model of matter

- In 1877 JJ Thomson proposed the “plum pudding” model of the atom
  - A positive charged “cake” of uniform density with tiny negative “raisins” distributed throughout
  - Based on Thomson’s earlier experiment demonstrating the existence of point like electrons
- In 1911 Ernest Rutherford and a team of scientist set out to determine the distribution of electrons in the plum pudding model of the atom
  - The Rutherford team decided to bombard gold foil with high energy alpha particles
    - Helium nuclei (2 protons and 2 neutrons)
    - Discovered by Marie and Pierre Curie



Rutherford's Gold Foil experiment

- Rutherford expected the heavy alpha particles to rip through the gold foil like a bullet through tissue paper!
  - Instead some alpha particles bounced back or were deflected at large angles
  - "It was quite the most incredible event that has ever happened to me in my life."
  - Rutherford proposed the existence of a nucleus that was massive and much smaller than the atom
- How did Rutherford arrive at this conclusion, and how did he make his estimate for the size of the nucleus?
  - Examining the interaction as an elastic collision



Computationally modelling the interaction

- We could solve for the final momentum by using conservation of momentum and energy as Rutherford did.
    - It is easier to model this in computationally using the electric force between a gold nucleus and an alpha particle
    - https://www.glowscript.org/#/user/ed/folder/My_Programs/program/Rutherford