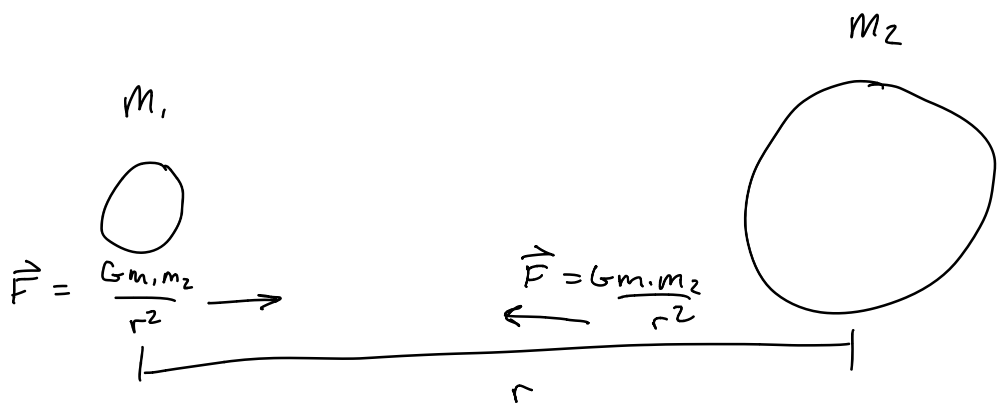
In our discussion of gravity & electromagnetic force, we noticed something

If Force <u>ON 2</u> <u>BY 1</u> $= \vec{F}$

Then

Force <u>ON 1</u> <u>BY 2</u> $= -\vec{F}$

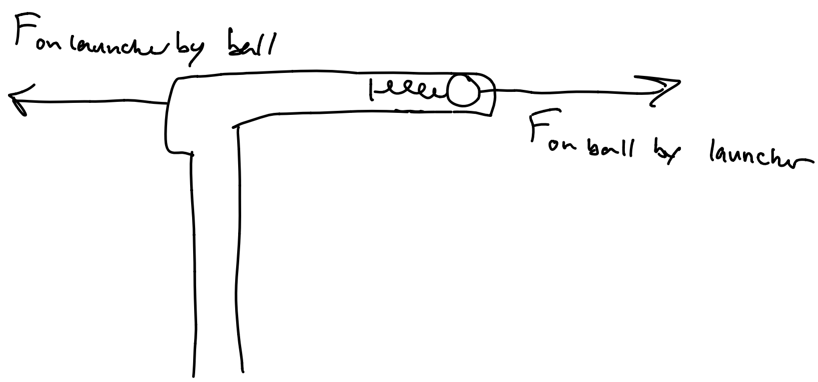


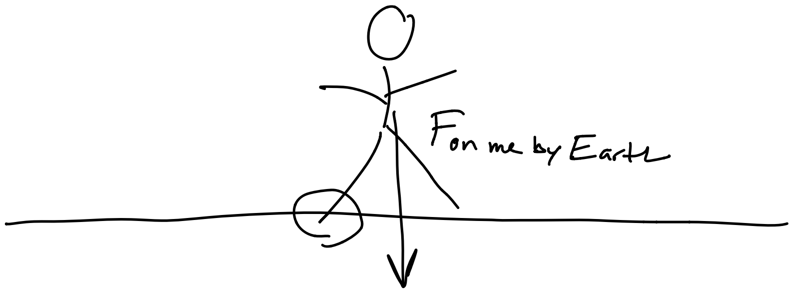
This is a specific example of a much more general principle

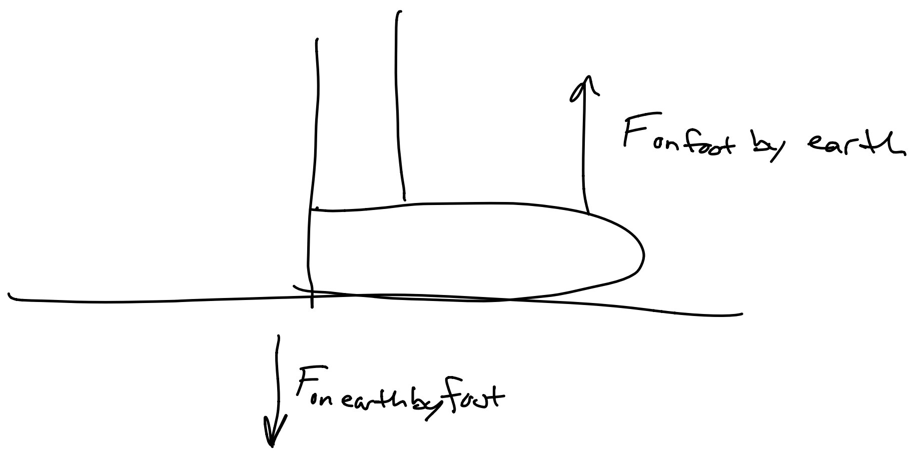
Newton's 3^{rd} Law (Reciprocity)

"If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on object A"

Examples: Projectile launcher (demo)

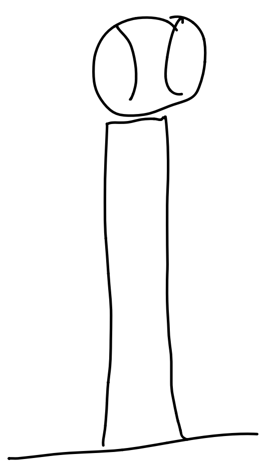


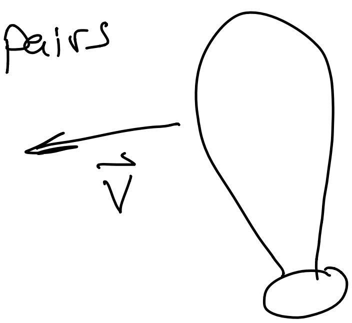




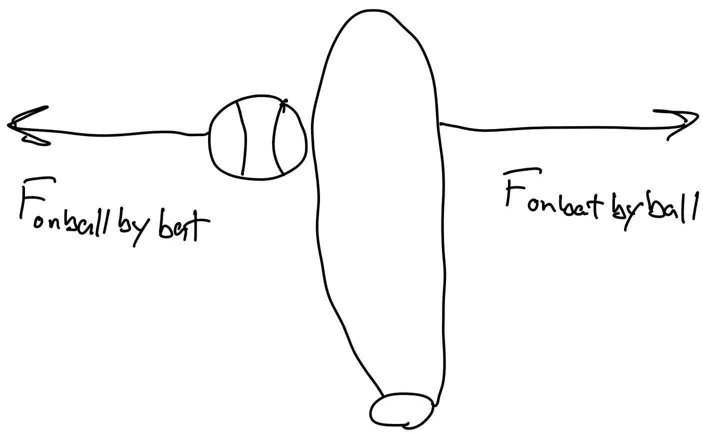
- Forces always come in pairs

Intuition





- When they collide, the bat will exert a force on the ball, & ball on the bat
- Why is the ball's motion afterwards so different from the bat?

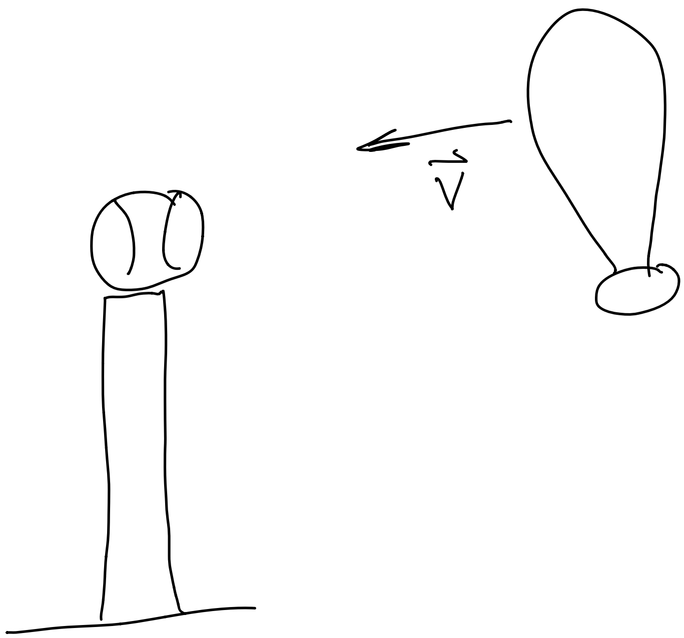


Mass of ball is small

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

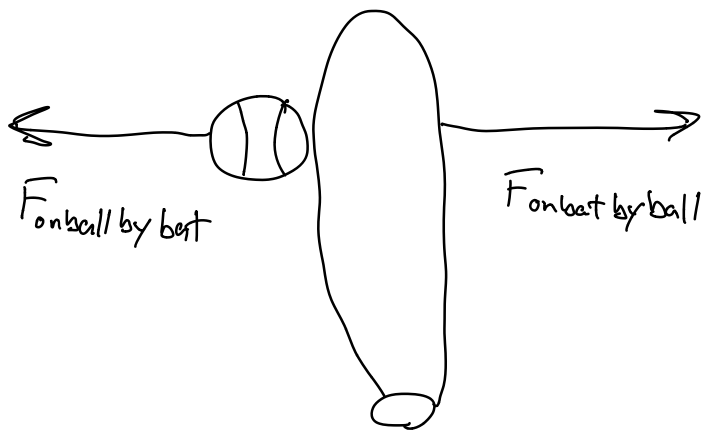
Force on bat is transferred to the bat holder, who is much more massive than the ball

- Because the ball is the one to fly off, it makes sense to us that a force is exerted on the ball
- We don't observe much force on the bat



Is the bat moving toward the ball, or is the ball moving toward the bat?

- From the ball's perspective, bat moves toward ball + exerts a force
- From the bat's perspective bat is stationary + ball is moving toward it + exerts a force on it
- Both perspectives are valid



Forces are equal & opposite

$$\vec{F}_{\text{on ball}} = -\vec{F}_{\text{on bat}}$$

$$\vec{F}_{\text{net}} = \vec{F}_{\text{on ball}} + \vec{F}_{\text{on bat}} = 0$$

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

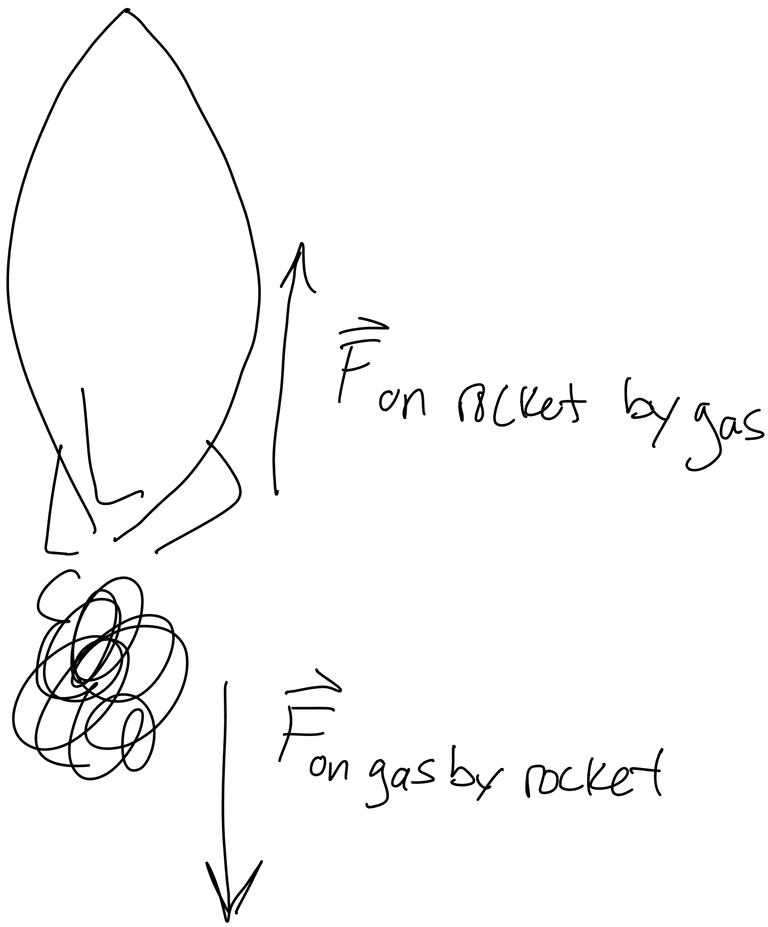
???

Forces act on different objects!

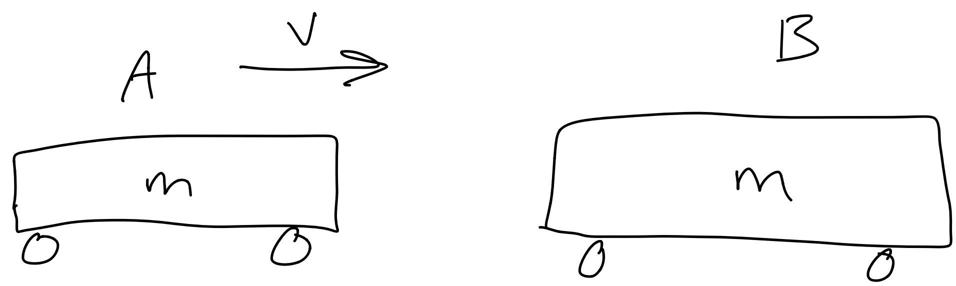
$$\vec{F}_{\text{net, ball}} = \vec{F}_{\text{on ball}}$$

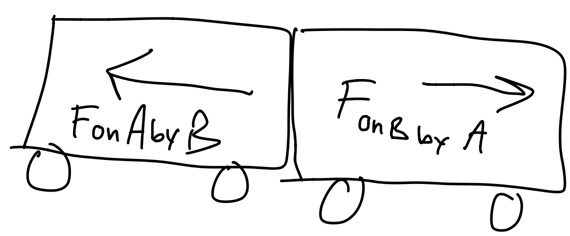
$$\vec{F}_{\text{net, bat}} = \vec{F}_{\text{on bat}}$$

Ultimate example: Rockets



Ex: two carts





After

$$\vec{P}_A = \vec{P}_{A,i} + \vec{F}_{oAbyB} \Delta t$$

$$\vec{P}_B = P_{B,i} + \vec{F}_{onBbyA} \Delta t$$

A loses momentum

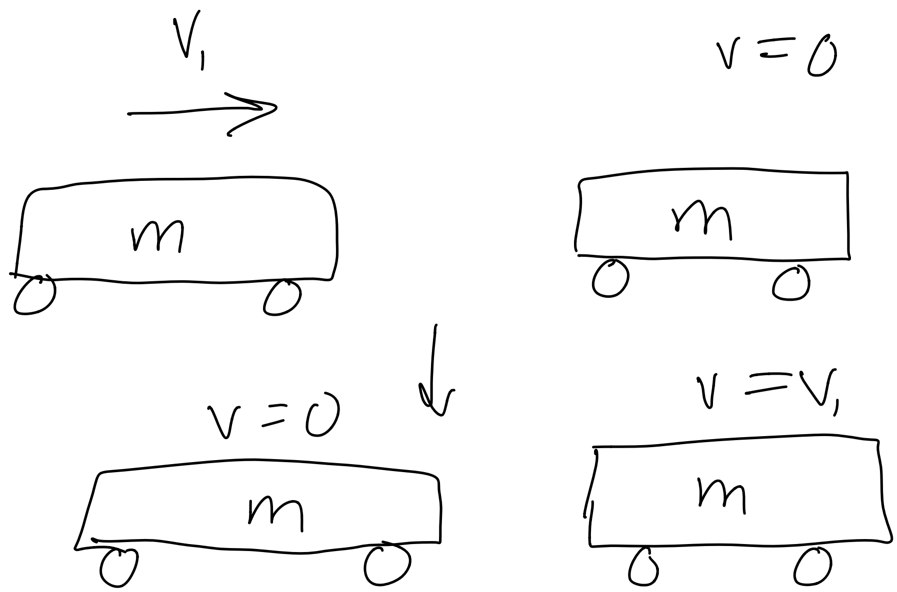
B gains momentum

Momentum gained by B is equal to momentum lost by A

Total momentum is constent

Momentum cannot be created or destroyed, only transferred

$\Delta p_{universe} = 0$



$p_i = mv_1$

$p_f = mv_1$

$\Delta p = p_f - p_i = 0$

Ex: Drop a golf ball from a metr high

Start at rest ($p_i = 0$)

What is p just before hitting the ground?

$p(t) = p_i + F_y t$

$p(t) = 0 - mgt$

$y(t) = y_i + v_i \sin\theta \, t - \frac{1}{2} g t^2$

$$0 = 1m - \frac{1}{2} g t^2$$

$$t^2 = 2 \frac{1m}{g}$$

$$t = \sqrt{\frac{2(1m)}{9.8\,m/s^2}} = 0.45\ s$$

$$p_f = -mgt$$

$$= -(0.1)(9.8)(0.45)$$

$$\boxed{p_f = -0.44\ kgm/s}$$

$$\Delta p = p_f - p_i$$

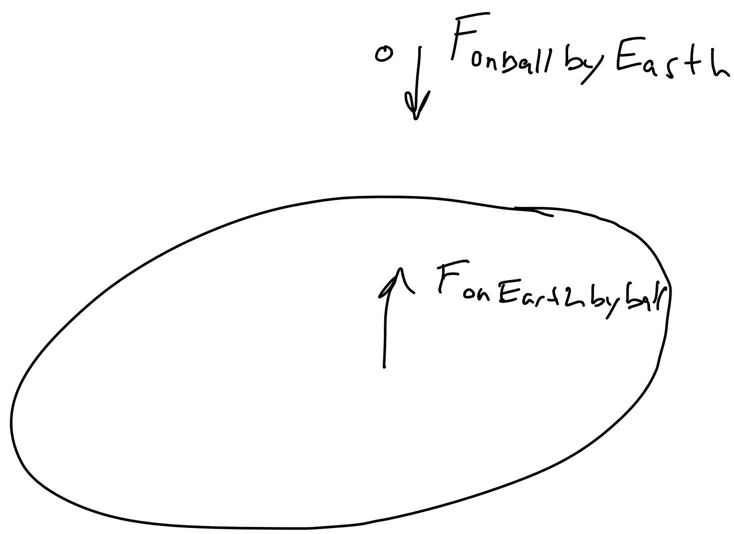
$$= -0.44 - 0$$

$$\Delta p = -0.44\ \frac{kg\,m}{s}$$

$$v = 4.4\ m/s$$

Did we gain momentum out of nowhere?

Newton's 3^{rd}



$$p_f = p_i + mgt$$

$$= 0 + (0.1)(9.8)(0.45)$$

$$\Delta p = 0.44 \ \frac{kg\,m}{s}$$

$$v = 0.44 / 6\times10^{24}$$

$$v = 7.3\times10^{-26} \ m/s$$

$$\Delta p_{total} = \Delta p_{ball} + \Delta p_{earth} + \cancel{\Delta p_{other}}$$

system vs surroundings

In the first example, our system was the ball, and the Earth was our surrounding

In second, system was the Earth, + the ball was our surrounding

Conservation of momentum

$$\Delta p_{total} = \Delta p_{sys} + \Delta p_{surr} = 0$$

$$\boxed{\Delta p_{sys} + \Delta p_{sur} = 0}$$

$$\Delta p_{sys} = \vec{F}_{net} \Delta t$$