From last time

- Defined **mass *m*** and **inertia**:
  - Mass is amount of inertia of a body
  - Measured in kg
- Defined ***momentum p:***
  - *p=mv*, momentum is said to be conserved
- Defined **force *F***:
  - Something that changes a body's velocity
  - Can transfer momentum from one body to another
- Started exploring the meaning of these concepts using **Newton's Laws**

Mass

- Define ***mass*** to be 'the amount of inertia of an object'.
- Can also say mass characterizes the amount of matter in an object.
- Symbol for mass usually *m*
- Unit of mass is the kilogram (kg).

- Said before that $a \propto F$
- Find experimentally that

$$\text{Acceleration} = \frac{\text{Force}}{\text{Mass}}$$

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

Force, weight, and mass

$$F = ma \Rightarrow F = (\text{kg}) \times (\text{m/s}^2)$$

$$= kg - m/s^2 \equiv \text{Newton}$$

- 1 Newton = force required to accelerate a 1 kg mass at 1 m/s^2.

But then what is weight?
—Weight is a force, measured in Newton's
—It is the net force of gravity on a body.
—*F=mg, g=F*/m

Is 'pounds' really weight?

- In the English system (feet, pounds, seconds), pounds are a measure of ***force.***
- So it is correct to say my weight is 170 pounds.
- Then what is my mass?

$$m = \frac{F}{g} = \frac{170 lbs}{32 ft/s^2} = 5.3 \text{ slugs!!}$$

Momentum conservation

- We said before that an impressed force changes the momentum of an object.
- We also said that momentum is conserved.
- This means the momentum of the object applying the force must have decreased.
- According to Newton, there must be some force acting on that object to cause the momentum change.

Newton's third law

- This is the basis for Newton's third law:

To every action there is always opposed an equal reaction.

This is momentum conservation in the language of forces.

Newton's laws

<u>1st law</u>: ***Law of inertia***

Every object continues in its state of rest, or uniform motion in a straight line, unless acted upon by a force.

<u>2nd law</u>: ***F=ma*, or *a=F/m***

The acceleration of a body along a direction is

- proportional to the total force along that direction, and
- inversely the mass of the body

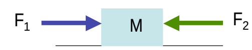
<u>3rd law</u>: ***Action and reaction***

For every action there is an equal an opposite reaction.

Example: More than one force

M=10 kg, F_1=200 N
Find *a*

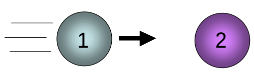
$a = F_{net}/M = 200N/10kg = 20\ m/s^2$



M=10 kg F_1=200 N F_2 = 100 N
Find *a*

$a = F_{net}/M = (200N-100N)/10kg = 10\ m/s^2$

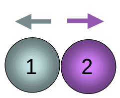
Colliding balls again



Before collision:

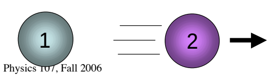
During collision

Force on ball 1 decelerates it to zero velocity



Force on ball 2 accelerates it

After collision:



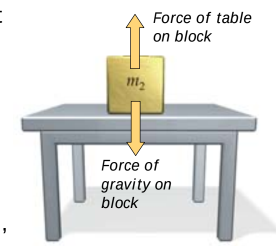
Balancing forces

Force of gravity acts downward on the block.

But since the block is not accelerating. The net (total) force must be *zero*.

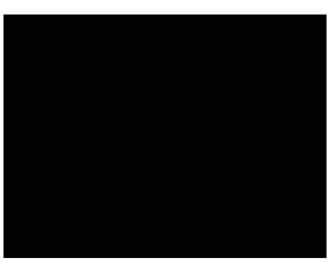
Another force is present, which balances the gravitational force.

It is exerted by the table, on the block.



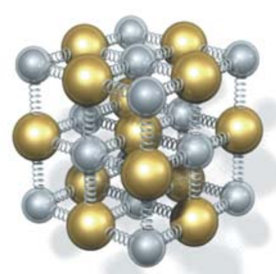
How can the table exert a force?

- The interaction between the table and the block is a microscopic one.



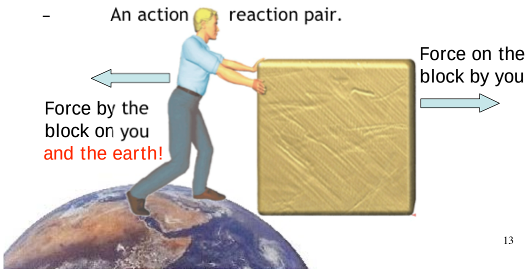
Force of table on block

- The table can compress, bend, and flex by distorting the atomic positions.
- The atomic bond is like a spring and it exerts a force on the block.
- All forces arise at the atomic (or smaller) scale.



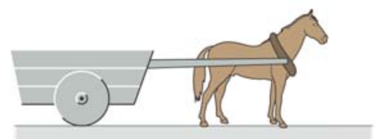
3rd law: Law of force pairs

- ***Every*** force is an interaction between two objects
- ***Each*** of the bodies exerts a force on the other.
- The forces are equal and opposite
  - An action reaction pair.



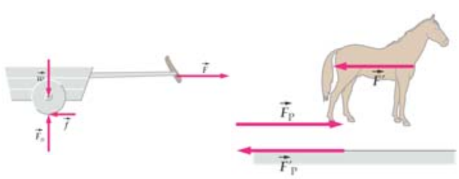
Identifying forces

- If horse exerts force on cart, and cart exerts equal and opposite force on horse, how can the horse and cart move?

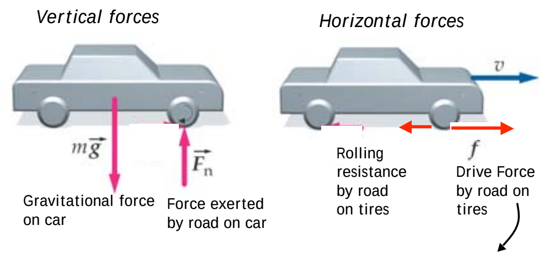


Keep the forces straight!

- For motion of cart, need to identify the net force on the **cart.**
- Net horizontal force is force from horse, combined with frictional force of wheels.



How can a car move?

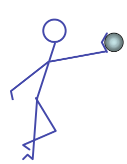


Wheels push push backward against the road, Road pushes forward on the tire

Rockets

- I apply a force to a ball for a short time Δt to get it to move.
- During that time, the ball exerts an equal and opposite force on me!

The forces cause the ball and I to move in opposite directions



Why did the ball and I move?

The forces resulted in accelerations during the short time Δt

Me: $\text{acceleration} = \frac{\text{Force}}{\text{my mass}}$

Ball: $\text{acceleration} = \frac{\text{Force}}{\text{ball mass}}$

My acceleration is smaller since my mass is much larger.

The acceleration changes my velocity.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

$$(\text{acceleration}) \times (\text{change in time}) = \text{change in velocity}$$

$$\frac{\text{Force}}{\text{mass}} \times (\text{change in time}) = \text{change in velocity}$$

Another explanation

- Before the throw,
  both the ball and I have zero momentum.
- So the total momentum is zero.

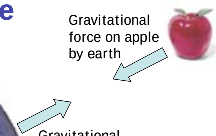
The total momentum is conserved,
so after the throw the momenta must cancel

(my momentum) + (ball momentum) = 0

(my mass) x (my velocity) = — (ball mass) x (ball velocity)

$$\text{(my velocity)} = -\text{(ball velocity)} \times \frac{\text{ball mass}}{\text{my mass}}$$

Gravitational force



These forces are equal and opposite,

$$m_{Earth} a_{Earth} = m_{apple} a_{apple}$$

$$\Rightarrow \frac{a_{Earth}}{a_{apple}} = \frac{m_{apple}}{m_{Earth}}$$

But m_{earth}=6x10^{24} kg

m_{apple}=1 kg

Equal accelerations

- If more massive bodies accelerate more slowly with the same force…

… why do *all* bodies fall the same, independent of mass?

$$F_{gravity} = mg$$

- Gravitational force on a body depends on its mass:
- Therefore acceleration is independent of mass:

$$a = \frac{F_{gravity}}{m} = \frac{mg}{m} = g$$

A fortunate coincidence

- A force exactly proportional to mass, so that everything cancels nicely.
- But a bit unusual.
- Einstein threw out the gravitational force entirely, attributing the observed acceleration to a distortion of space-time.