

# Physics 100

## Today

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**Finish Chapter 4: Newton's Second Law**

**Start Chapter 5: Newton's Third Law**

## First, let's clarify notion of a force:

Previously defined force as a push or pull. Better to think of force as an **interaction** between two objects.

Eg. I push on the table, it pushes back on me with an equal and opposite force on me. If on ice (no friction), I'd slide backwards. This *force pair constitutes a single interaction*.

(More examples very soon)

You can't push anything without it pushing back on you !

**Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.**

Newton's 3<sup>rd</sup> Law - often called "**action-reaction**"

Eg. Leaning against a wall.

You push against the wall. The wall is also pushing on you, equally hard – normal/support force.



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Now place a piece of paper between the wall and hand. Push on it – it doesn't accelerate → must be zero net force. The wall is pushing equally as hard (normal force) on the paper in the opposite direction to your hand, resulting in zero  $F_{net}$ .

This is more evident when hold a balloon against the wall – it is squashed on both sides.

E.g. You pull on a cart. It accelerates. The cart pulls back on you (you feel the rope get tighter).

Can call your pull the “**action**” and cart’s pull the “**reaction**”.  
Or, the other way around.

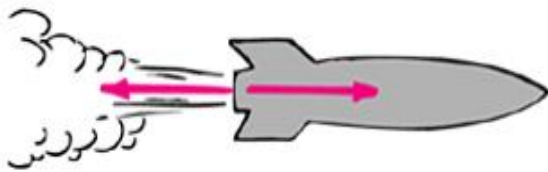
- Newton’s 3<sup>rd</sup> law means that **forces always come in action-reaction pairs**. It doesn’t matter which is called the action and which is called the reaction.
- Important Note: **Action-reaction pairs *never* act on the same object.**

So you *can’t* use their equal-but-opposite nature to conclude something is in equilibrium: if  $F_{net}=0$ , that’s for forces acting on the same object.

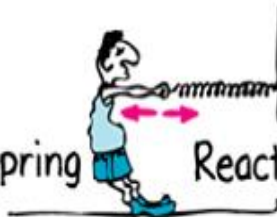
# Examples of action-reaction force pairs



Action: tire pushes on road    Reaction: road pushes on tire



Action: rocket pushes on gas    Reaction: gas pushes on rocket



Action: man pulls on spring    Reaction: spring pulls on man

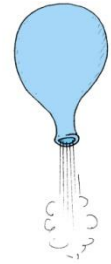


Action: earth pulls on ball

Reaction: ball pulls on earth

In fact it is the road's push that makes the car go forward. Same when we walk – push back on floor, floor pushes us forward. (These forces are frictional).

**Demo:** blow up a balloon and release it. Same principle as rocket



# Clicker Question

# Another Question

What are the action-reaction pairs once the ball is in the air?

First note there are two interactions:

(i) one with the earth's gravity and

(ii) the other with the air.

(i) Action (or reaction): Earth pulls down on ball (weight)

Reaction (or action): Ball pulls up on Earth.

(ii) Action: Air pushes ball backwards (air resistance)

Reaction: Ball pushes air forwards

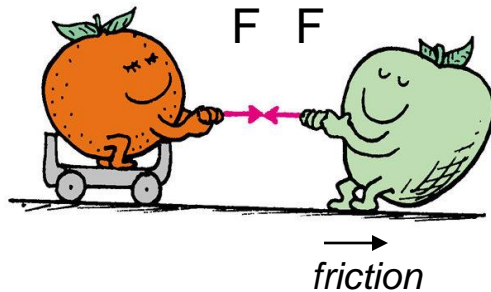
# **Clicker Question**



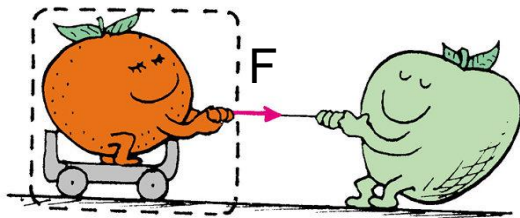
# **Clicker Question**

## **Another Clicker Question**

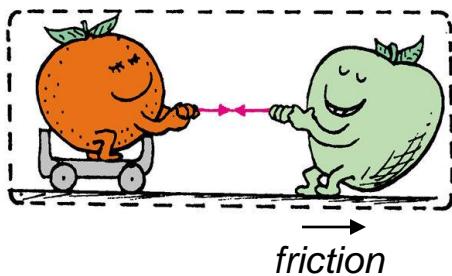
Let's consider the force pair between the "apple" and "orange" below:



Apple exerts a force  $F$  on orange, so orange accelerates. Simultaneously, orange exerts equal force in the opposite dir. on the apple (but apple may not accelerate because of friction on his feet).



- Consider now orange as the "system". Apple's pull on orange,  $F$ , is an external force and accelerates the system(=orange) to the right.



- Consider now the apple+orange as one system. Then the only external force is friction. Action and reaction are both within the system & cancel to zero within system . System accelerates to the right.
- If friction =0, acc. of system =0 (eg if they were on ice). Apple and orange would move closer to each other but system's center of mass wouldn't move.

# Questions

(1) A pen at rest. It is made up of millions of molecules, all pulling on each other - cohesive inter-atomic forces present in any solid. Why doesn't the pen accelerate spontaneously due to these forces?

Because each of these is part of an action-reaction pair within the pen. They always add to zero within the system. The pen will remain at rest unless an external force acts on it.

(2) The earth's gravity pulls on the moon. What is the reaction force to this?

Ans: The moon's pull on the earth.

**Note:** It is simpler to think of this as **one interaction** – the Earth and moon simultaneously pull on each other (action-reaction), each with the same amount of gravitational force.

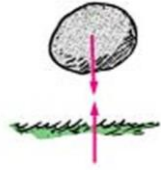
(3) Consider for simplicity, the earth and moon as the only bodies in the universe.

a) What is the net force on the earth?      The moon's gravitational pull

b) What is the net force on the earth+moon system?

0. Action and reaction cancel within the system

# More on action-reaction...



- If all forces come in pairs, then how come the earth doesn't accelerate towards apples falling from trees?

Actually it does! But it is not noticeable or measurable because the earth's mass is so large (*c.f. earlier clicker question*):

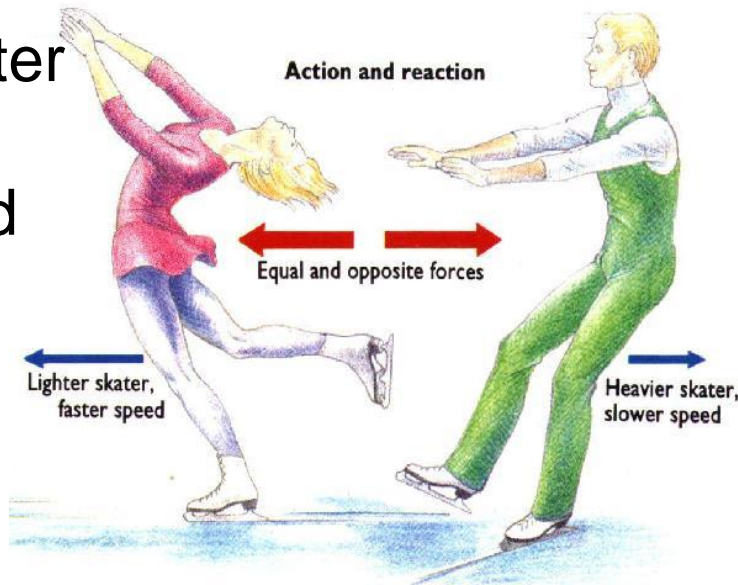
The earth exerts force =  $mg$  on the apple. This interaction gives apple acc =  $F/m = 9.8 \text{ m/s}^2$ .

← mass of apple

The apple exerts *just as much force* on the earth,  $mg$ . But to get acc of earth, this gets divided by  $M$ , the mass of the earth: earth's acc. =  $(mg)/M \sim \text{tiny}$ .

# And more on action-reaction...

- E.g. A skater pushes another and recoils



The force exerted on the woman is just as large as the reaction force on the man, so he also moves backwards. But his acceleration is less since his mass is larger.

- E.g. “Kick”, or recoil, of a fired rifle:



$$a_{bullet} = F/m_{bullet}$$

Since  $m_{rifle} \gg m_{bullet}$ , but same  $F$ ,  $a_{rifle} \ll a_{bullet}$

$$a_{rifle} = F/m_{rifle}$$

- Same principle behind a rocket (or earlier balloon demo) – it continually recoils from the ejected gas.

# Clicker Question

# Summary of Newton's Three Laws

- An object tends to remain at rest, or, if moving, to continue moving at constant speed in a straight line (**1<sup>st</sup> Law**).  
Objects tend to resist changes in motion (**inertia**) – **mass** measures this.
- (**2<sup>nd</sup> Law**) When there is a net force on an object, it will accelerate:  
 $a = F_{net}/m$ ,  $a$  is in the same direction as  $F_{net}$ .
- Falling in vacuum (**free-fall**), the only force is gravity,  $mg$ , and every object falls at the same rate,  $g = 9.8 \text{ m/s}^2$
- Falling in air,  $F_{net} = mg - R$ , acceleration is *less than*  $g$ .  $R$  is greater for objects with more frontal area, and for larger speeds. **Terminal speed** is reached when  $R = mg$ , so is later for heavier objects, which therefore accelerate more and hit ground faster.
- (**3<sup>rd</sup> Law**) Whenever any object A exerts force on object B, B exerts equal and opposite force on A. It is a **single interaction**, forces come in pairs. Action and reaction always act on different objects.



# Vectors

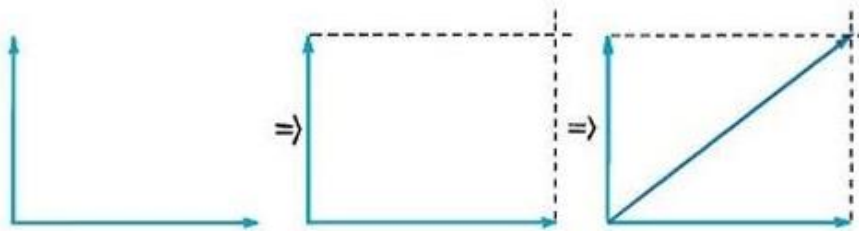
- Vector = quantity with magnitude and direction, eg velocity, force, acceleration....  
Can represent by an arrow (length indicates magnitude)
- Scalar - has magnitude only, eg speed, mass, volume..
- Often we want to add vectors: eg if want to find net force, when several forces acting, or, to find resulting velocity when a plane is headed in a certain direction, but there is a wind blowing in another..
- If the two vectors are in the same direction – can just add. If in opposite directions, subtract.

$$\longrightarrow + \longrightarrow = \longrightarrow$$

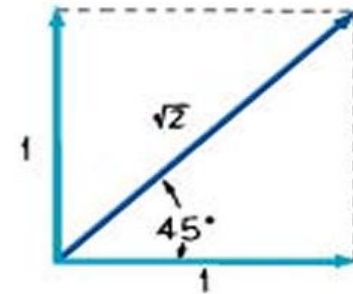
$$\longrightarrow + \longleftarrow = \longleftarrow$$

More generally, use **parallelogram rule** to add to get the **resultant**: construct such that two adjacent sides are the two vectors – the diagonal shows the resultant.

Simplest case: when the two vectors to be added are at right angles:

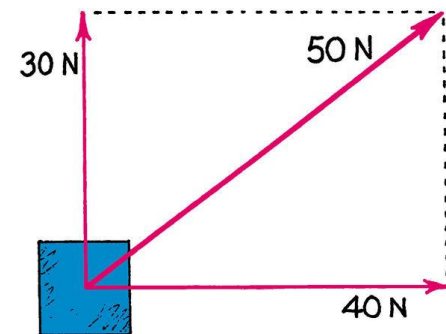


The parallelogram is a rectangle in this case.



- When the two vectors are at right-angles and have the same magnitude, then the parallelogram is a square:

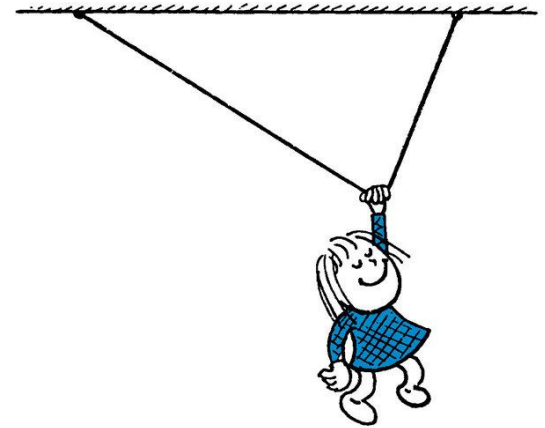
- Pythagorean triples can also simplify addition: eg. Top view of 30 N and 40 N horizontal forces pulling on a box, gives a resultant force of 50 N in direction shown:



- Vector components: “resolve” any vector into two components at right-angles to each other. We won’t study this in this course, but do read about it in your book if you are interested!

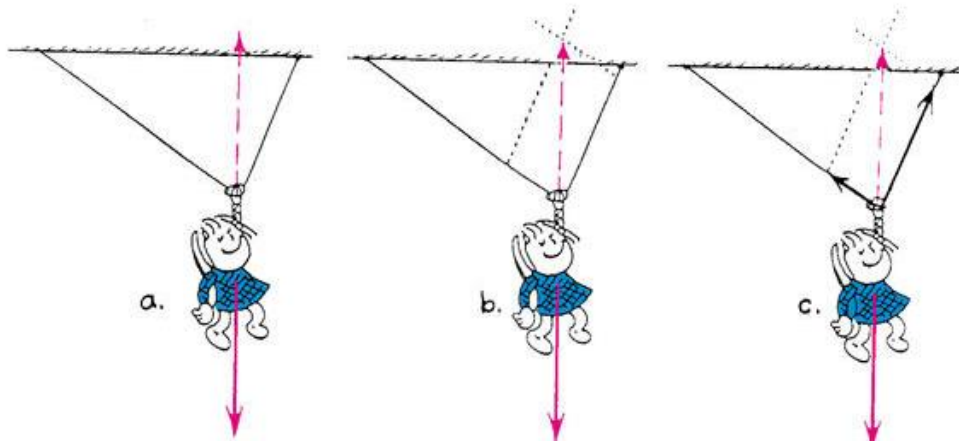
# Example

The girl is hanging, at rest, from a clothes line. Which side of the line is more likely to break?



First, identify forces: Three forces are acting on her – downward weight, tension in left line, and tension in right line. The question is asking, which tension is greater.

Because she's at rest, the net force must be 0. The upward tensions must sum to her weight. Make parallelogram with sides along the rope tensions, whose diagonal is the desired upward resultant:



So, larger tension in the right line (more vertical), so it is more likely to break.

# Clicker Question

# Example