Section 1.5. Newton's Third Law

"For every action there is an equal but opposite reaction."

That's how Newton expressed it, but his archaic language may create some confusion or misconceptions.

- What is meant by "action"?

Newton's word "action" is what we now call *force*.

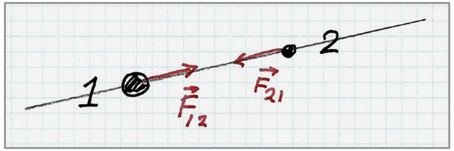
- When does the reaction occur?

The two forces (action and reaction) are perfectly simultaneous.

- If the two forces are simultaneous, then which one is the action and which one is the reaction?

You could call either force the action and the other one the reaction.

A modern statement of Newton's third law, trying to avoid these confusions, is:



"

If object 1 exerts a force $\mathbf{F}_{21}$ on object 2, then object 2 exerts a reaction force $\mathbf{F}_{12}$ on object 1 given by

$$\mathbf{F}_{12} = -\mathbf{F}_{21} .$$

"

(Taylor)

Figure 1.5

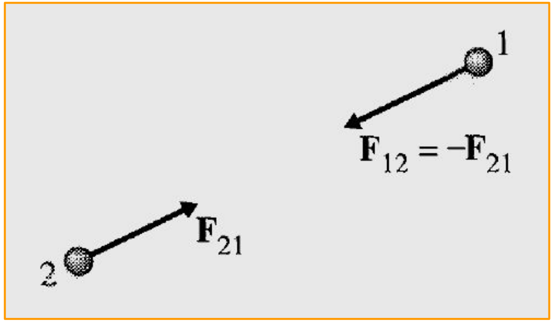
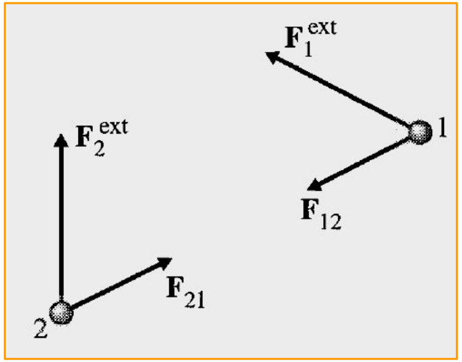


Figure 1.6



•*The external forces do not need to be equal but opposite.* •*"Internal forces", i. e., action-reaction pairs, must be equal but opposite.*

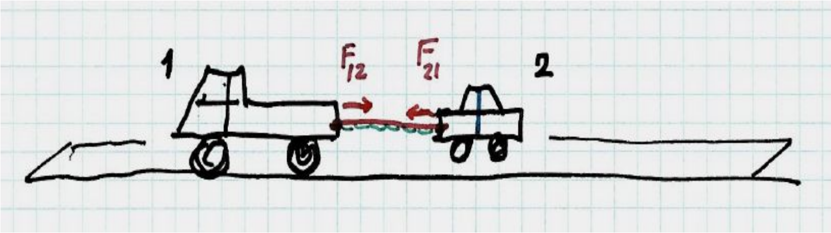
A famous puzzle:

When the tow truck starts to accelerate and pull the car, which force in the figure below is stronger?

These two forces are equal but opposite.

But if the forces are equal but opposite, how can the vehicles begin to move and accelerate?

Let's think about it carefully...



The tow truck (object 1, mass = 3000 kg) pulls the car (object 2, mass = 1000 kg) with a tow rope.

When the truck accelerates to the left, the rope pulls the car to the left with a force $\mathbf{F}_{21}$, and the rope pulls the truck to the right with a force $\mathbf{F}_{12}$.

By Newton's third law, $\mathbf{F}_{12} = -\mathbf{F}_{21}$.

("tension" in the rope)

The two forces are equal but opposite.

But if the forces are equal but opposite, how can the vehicles begin to move and accelerate?

There are other forces acting, e.g., friction between the tow truck tires and the road.

The truck tires are pushing the Earth backwards, and the Earth pushes the tires forward. Because the rubber is ≈ inelastic, the truck accelerates forward.

What would happen if the truck is on a frictionless surface, like an icy road?

(The answer to this question ***proves*** Newton's third law.)

The important consequence of Newton's third law

In an interaction between two isolated particles, the total momentum is constant.

Proof:

Recall from PHY 183,

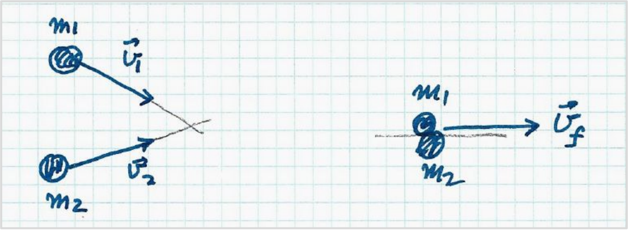
$$\mathbf{p}_1 = m_1 \boldsymbol{v}_1 \qquad \text{and} \qquad \mathbf{p}_2 = m_2 \boldsymbol{v}_2 .$$

The total momentum is $\mathbf{P} = \mathbf{p}_1 + \mathbf{p}_2$.

$$\begin{aligned} \frac{d\vec{P}}{dt} &= m_1 \frac{d\vec{v}_1}{dt} + m_2 \frac{d\vec{v}_2}{dt} \\ &= \vec{F}_1 + \vec{F}_2 \\ &= \vec{F}_{12} + \vec{F}_{21} \qquad \text{(Isolated system)} \\ &= 0 \qquad \text{(Newton's 3rd law)} \end{aligned}$$

Example: *a perfectly inelastic collision*

See the figure. The two objects stick together after the collision.



Calculate the final velocity.

Principle : Momentum is conserved.

$$m_1 \vec{v}_1 + m_2 \vec{v}_2 = (m_1 + m_2)\, \vec{v}_f$$

$$\to \quad \vec{v}_f = \frac{m_1}{m_1 + m_2} \vec{v}_1 + \frac{m_2}{m_1 + m_2} \vec{v}_2$$

We'll study a lot more about conservation of momentum in Chapter 3.

The validity of Newton's third law

We know from many experiments that momentum is conserved for an isolated system.

So Newton's third law must be valid.

But it can't always be valid!

See Taylor: **" the third law cannot be valid once relativity becomes important." (page 21)**

The magnetic force between two moving charges does not obey Newton's third law.

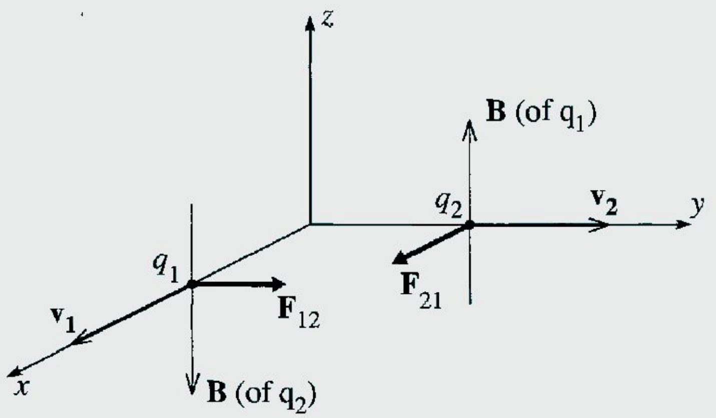


Figure 1.8 Each of the positive charges q_1 and q_2 produces a magnetic field that exerts a force on the other charge. The resulting magnetic forces $\mathbf{F}_{12}$ and $\mathbf{F}_{21}$ do not obey Newton's third law.

Comments:
/1/ Momentum is conserved, but we must include the momentum of the E.M. radiation fields;
/2/ The magnetic force is order v^2/c^2 compared to the electric force.
/3/ In "classical mechanics", Newton's third law is always valid.

<u>Homework Assignment #2</u>

<u>Instructions</u>

The due date is Friday, September 16.

Homework solutions must be handed in in class.

Staple the cover sheet, with answers where indicated, in front of your solutions.

<u>Computer problems.</u>

Your best bet is to use *Mathematica*.
It is available in many MSU microcomputer labs, e.g., 106 Farrell Hall or 1210 Anthony Hall.
If you are not familiar with *Mathematica*, then see the handout.

Homework Assignment #2
due in class Friday, September 16

[6] Problem 1.35 *
[7] Problem 1.38 **
[8] Problem 1.39 *
[9] Problem 1.44 *
[10] Problem 1.51 *** [computer]

Use the cover sheet.

Be sure to get the handouts:

1. Cover sheet for H assignment #2.
2. a Mathematica notebook to solve Taylor's Problem 1.50.