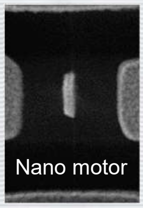
CHAPTER 3
Forces and Motion
Newton's Laws of Motion

We've been learning kinematics; describing motion without understanding what the cause of the motion was. Now we are going to learn dynamics!!



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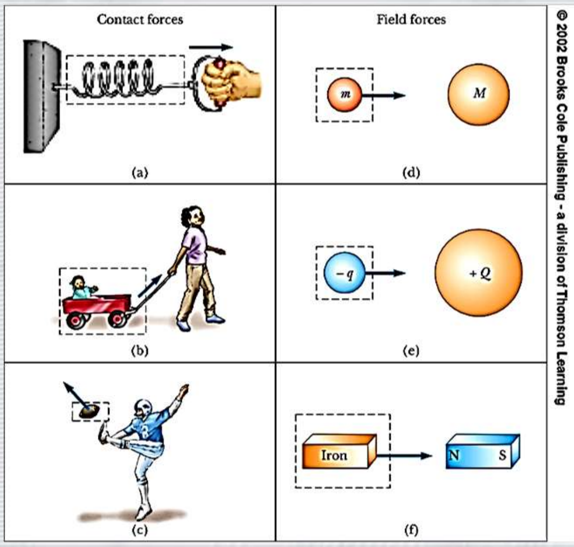
Forces

Can someone tell me what FORCE is?



- Usually a push or pull
- Vector
- Either contact or field force

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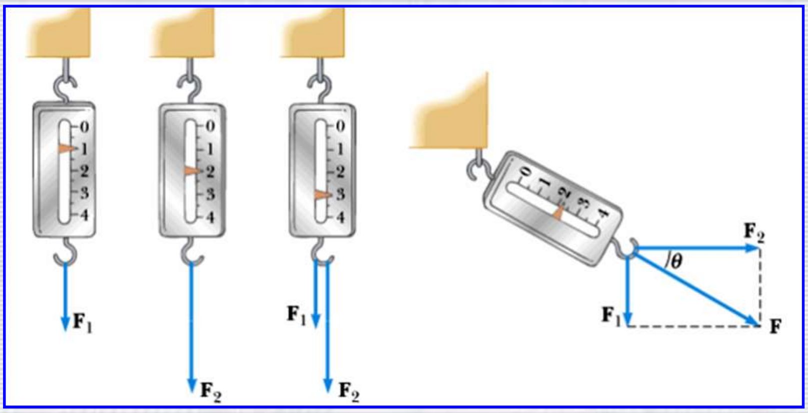
Measuring forces

- Forces are often measured by determining the elongation of a calibrated spring.

- Forces are **vectors**!! Remember vector addition.

- To calculate net force on an object you must use **vector addition**.



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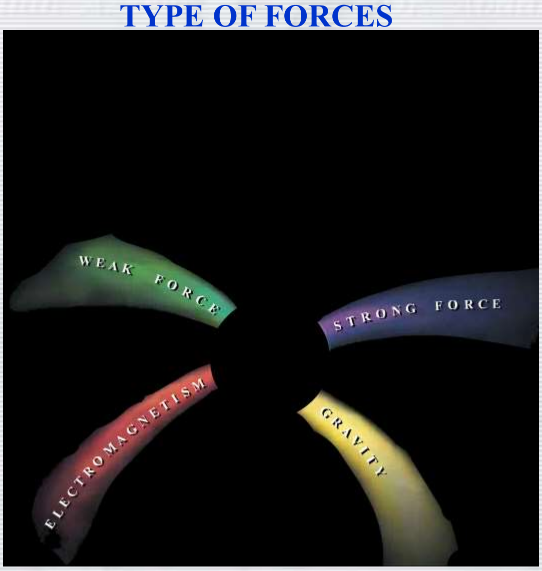
TYPE OF FORCES



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3.1 Newton's First Law of Motion:

An object continues in a state of rest or in a state of uniform motion at a constant speed along a straight line unless compelled to change that state by a net force.

In other words;

If the net force $\sum F$ exerted on an object is zero the object continues in its original state of motion. That is, if $\sum F = 0$, an object at rest remains at rest and an object moving with some velocity continues with the same velocity.

Why? Because objects have "inertia"

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3.2 MASS (INERTIA):

The "tendency" that Newton observed for objects at rest to stay at rest and objects in motion to stay in uniform motion in a straight line.

How do we measure inertia?

MASS

- A measure of the resistance of an object to changes in its motion due to a force
- Scalar
- SI units are kg

Don't confuse mass and weight

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Balanced forces:

We say that the NET force is zero!

Acceleration:

Remember that the word "acceleration" denotes an increase in velocity OR a decrease in velocity OR a change in the direction of velocity.

A force is any influence that change the velocity of an object

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3.4 Newton's 2nd Law of Motion

(very, very important)

The amount of acceleration (***a***) produced by a force (**F**) depends on the mass (**m**) of the object being accelerated.

Mathematically:

$$\mathbf{F} = \mathbf{m} \times \boldsymbol{a}$$

Alternatively:

$$a = F/m$$

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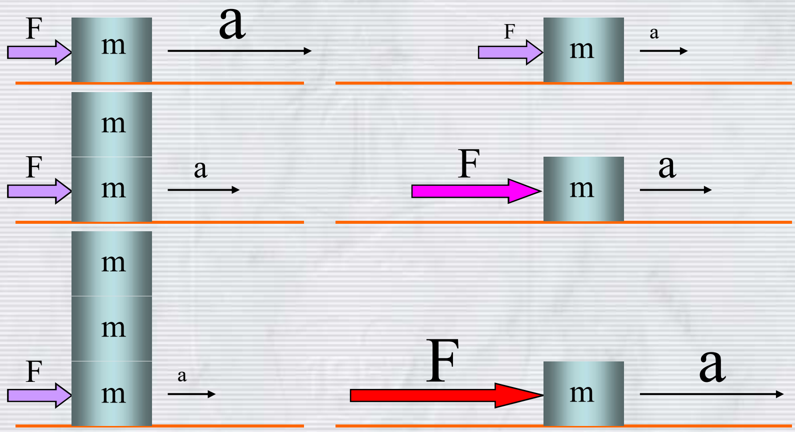
Newton's 2nd Law of Motion



$a \propto \frac{1}{m}$ $\qquad$ $\vec{a} \propto \vec{F}$ $\qquad$ *or* $\qquad$ $\vec{F} = m\vec{a}$

Newton's 2nd Law of Motion

The acceleration of an object is directly proportional to the **net force** acting on it and inversely proportional to its mass.

$$\sum \vec{F} = m \cdot \vec{a}$$

$$F_x = m \cdot a_x \qquad F_y = m \cdot a_y \qquad F_z = m \cdot a_z$$

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Units of Force

$F = m \times a$

$= [kg] \times m/s^2]$

$\equiv [N]$

Standard Unit: Newton

One Newton: The force required to accelerate a 1 kg mass by 1 m/s^2

3.6 British Units of Mass and Force

Table 3.1 Units of mass and weight

System of units	Unit of mass	Unit of weight	Acceleration of gravity g	To find mass m given weight w	To find weight w given mass m
SI	Kilogram (kg)	Newton (N)	9.80 m/s^2	$m\,(kg) = \frac{w(N)}{9.80\ m/s^2}$	$w\,(N) = m\,(kg) \times 9.80\ m/s^2$
British	Slug	Pound (lb)	32.2 ft/s^2	$m\,(slugs) = \frac{w(lb)}{32.2\ ft/s^2}$	$w\,(lb) = m\,(slugs) \times 32.2\ ft/s^2$

Conversion of units: 1 slug = 14.6 kg; 1 kg = 0.0685 slug; 1 N = 0.225 lb; 1 lb = 4.45 N

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EXAMPLE 3.1

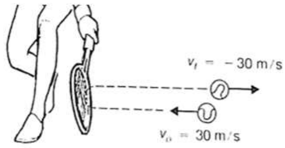
A 60-g tennis ball approaches a racket at 30 m/s, is in contact with the racket's strings for 5.0 ms (1 ms = 1 millisecond = 10^{-3} s), and then rebounds at 30 m/s (Fig. 3.11). What was the average force the racket exerted on the ball?

SOLUTION The tennis ball experienced a change in velocity of

$$\Delta v = v_f - v_0 = (-30\ \text{m/s}) - (30\ \text{m/s}) = -60\ \text{m/s}$$

so its acceleration was

$$a = \frac{\Delta v}{\Delta t} = \frac{-60\ \text{m/s}}{5.0 \times 10^{-3}\ \text{s}} = -1.2 \times 10^4\ \text{m/s}^2$$



The corresponding force is, since 60 g = 0.060 kg,

$$F = ma = (0.060\ \text{kg})(-1.2 \times 10^4\ \text{m/s}^2) = -720\ \text{N} = -0.72\ \text{kN}$$

105 Phys Dr. Abdallah M.Azzeer 13

EXAMPLE 3.2

During performances of the Bouglione Circus in 1976, John Tailor was fired from a compressed-air cannon whose barrel was 20 m long. Tailor emerged from the cannon (twice daily, three times on Saturdays and Sundays) at 40 m/s. If Tailor's mass was 70 kg, find the average force on him during the firing of the cannon (Fig. 3.12).

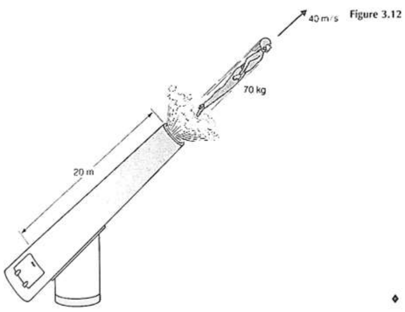
SOLUTION We start by finding Tailor's acceleration with the help of Eq. (1.12),

$$v_f^2 = v_0^2 + 2ax$$

Here $v_0 = 0$, $v_f = 40$ m/s, and $x = 20$ m, so

$$v_f^2 = 0 + 2ax$$

$$a = \frac{v_f^2}{2x} = \frac{(40\ \text{m/s})^2}{(2)(20\ \text{m})} = 40\ \text{m/s}^2$$



The corresponding average force is

$$F = ma = (70\ \text{kg})(40\ \text{m/s}^2) = 2800\ \text{N} = 2.8\ \text{kN}$$

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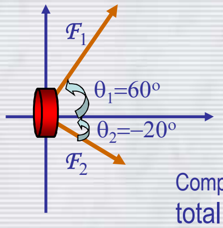
Example 5.1

Determine the magnitude and direction of acceleration of the puck whose mass is 0.30kg and is being pulled by two forces, **F_1** and **F_2**, as shown in the picture, whose magnitudes of the forces are 8.0 N and 5.0 N, respectively.



Components of $\mathcal{F}_1$

$$F_{1x} = \left|\vec{F_1}\right| \cos\theta_1 = 8.0 \times \cos(60°) = 4.0N$$

$$F_{1y} = \left|\vec{F_1}\right| \sin\theta_1 = 8.0 \times \sin(60°) = 6.9N$$

Components of $\mathcal{F}_2$

$$F_{2x} = \left|\vec{F_2}\right| \cos\theta_2 = 5.0 \times \cos(-20°) = 4.7N$$

$$F_{2y} = \left|\vec{F_2}\right| \sin\theta_2 = 5.0 \times \sin(-20°) = -1.7N$$

Components of total force $\mathcal{F}$

$$F_x = F_{1x} + F_{2x} = 4.0 + 4.7 = 8.7N = ma_x$$

$$F_y = F_{1y} + F_{2y} = 6.9 - 1.7 = 5.2N = ma_y$$

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Magnitude and direction of acceleration a

$$a_x = \frac{F_x}{m} = \frac{8.7}{0.3} = 29\ m/s^2$$

$$a_y = \frac{F_y}{m} = \frac{5.2}{0.3} = 17\ m/s^2$$

$$\left|\vec{a}\right| = \sqrt{(29)^2 + (17)^2} = 34\ m/s^2$$

$$\theta = tan^{-1}\left(\frac{a_y}{a_x}\right) = tan^{-1}\left(\frac{17}{29}\right) = 30°$$

Acceleration Vector a

$$\vec{a} = a_x\hat{i} + a_y\hat{j} = \left(29\hat{i} + 17\hat{j}\right) m/s^2$$

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3.5 The force of gravity and weight

Combining Law of gravity with Newton's 2nd Law of motion, we can derive an expression for the acceleration due to gravity.

- Objects are attracted to the Earth.
- This attractive force is the force of gravity F_g.

$$\vec{F}_g = m \cdot \vec{g}$$

- The magnitude of this force is called the weight of the object.
- The weight of an object is, thus mg.

The weight of an object can very with location (less weight on the moon than on earth, since g is smaller).

The mass of an object does not vary.

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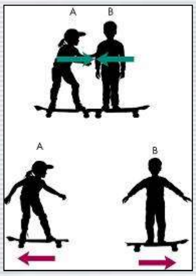
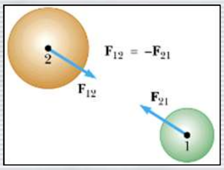
5.6 Newton's 3rd Law of Motion

Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body.



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

If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force F_{21} exerted by object 2 on object 1:



$$\vec{F}_{12} = -\vec{F}_{21}$$

Action and reaction forces always act on **different** objects.

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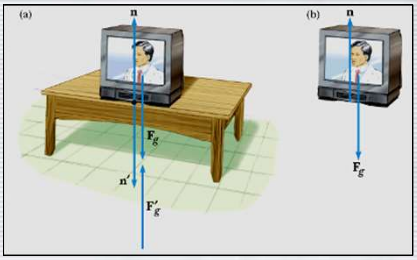
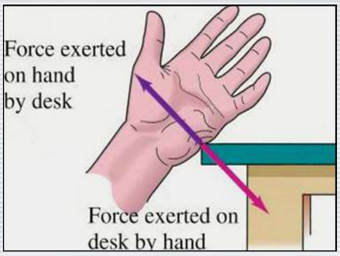
Where is the action and reaction force?





Action-Reaction Pairs: Act On ***Different*** Bodies

- **Forces exerted *BY* a body *DO NOT* (directly) influence its motion!!**
- **Forces exerted *ON* a body (*BY* some other body) *DO* influence its motion!!**
- **When discussing forces, use the words "BY" and "ON" carefully.**

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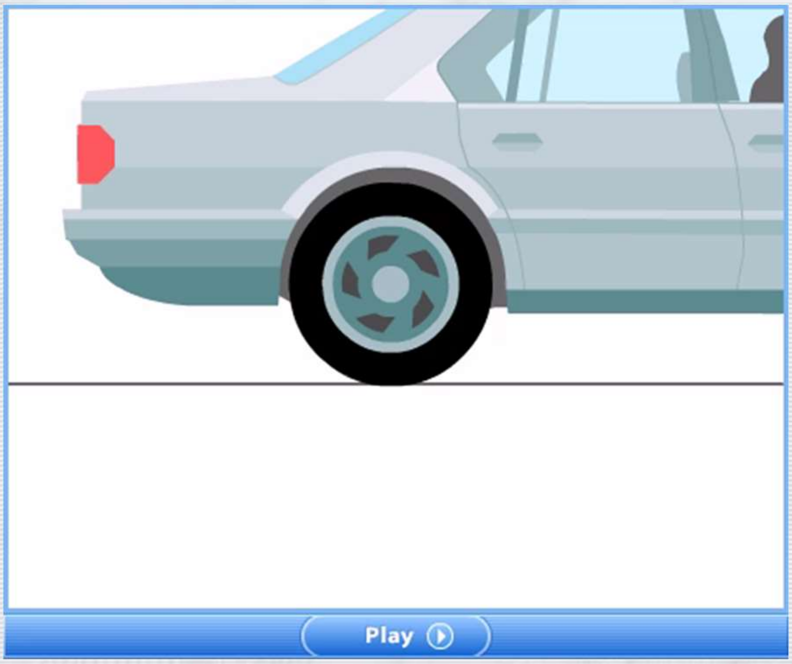

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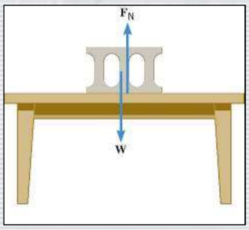
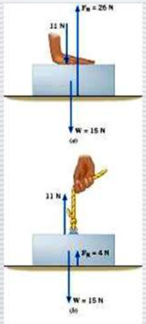
The Normal Force:



The normal force, F_N, is one component of the force that a surface exerts on an object with which it is in contact, namely, the component perpendicular to the surface.

The Normal Force: How to Measure



The magnitude of the normal force is a measure of how hard two objects push against each other.

The direction is perpendicular to the surface.

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- Where does the normal force come from?
- From the ***other body***!!!
- Does the normal force ***ALWAYS*** equal the weight?

NO!!!

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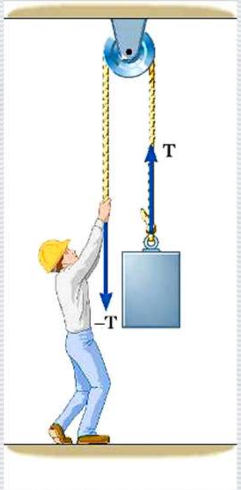
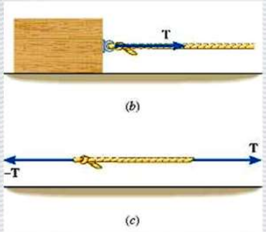
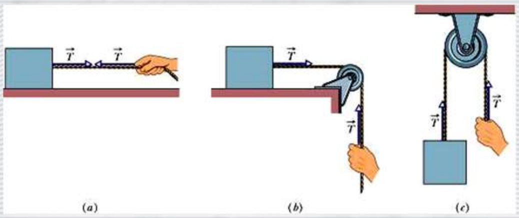
Tension

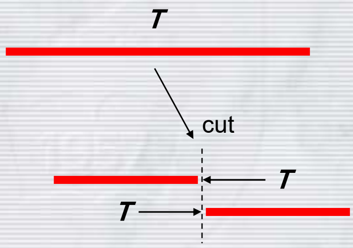






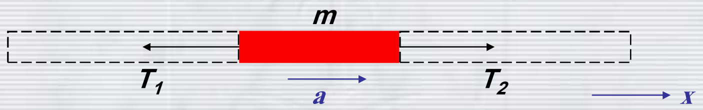
Some comments on strings/cords/cables/ropes

- Can be used to pull from a distance.
- *Tension (T)* at a certain position in a string is the magnitude of the force acting across a cross-section of the string at that position.
  - The force you would feel if you cut the string and grabbed the ends.
  - An action-reaction pair.



More on cords/strings/ropes/cables.

- **Consider a horizontal segment of string having mass *m*:**
  - **Draw a free-body diagram (ignore gravity as string is almost massless**



- **Using Newton's 2nd law (in *x* direction):**

$$F_{NET} = T_2 - T_1 = ma$$

- **So if $m = 0$ (i.e. the string is light) then $T_1 =$ □□ T_2**