Chapter 5

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The laws of motion

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Lecture 01

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Newton's Laws

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The Laws of Motion

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Kinematic: the description of an object in motion included its position, velocity, and acceleration.

Dynamic: studies the causes of motion.

Two main factors need to be addressed to answer questions about why the motion of an object will change.

- Forces acting on the object
- The mass of the object

Will start with three basic laws of motion, formulated by sir Isaac Newton

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Force ($\vec{F}$)

4

Forces are what cause an acceleration.

Forces are vectors.

SI units: Newton

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Classes of Forces

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Contact forces	Field forces
• involve physical contact between two objects ○ Pull or Push	• act through empty space ○ No physical contact is required ○ The gravitational force ○ The electric force ○ The magnetic force

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Fundamental Forces

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- Gravitational force: Between objects
- Electromagnetic forces: Between electric charges
- Nuclear force: Between subatomic particles
- Weak forces: Arise in certain radioactive decay processes
- Note: These are all field forces.

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Newton's First Law

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"In the absence of external forces, an object at rest remains at rest, and an object in motion remains in motion with constant velocity."

Mathematically:

$$\sum \vec{F} = 0$$

Objects in equilibrium are:

- at rest and remains at rest,
- moving with constant velocity.

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Newton's First Law

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Newton's First Law describes what happens in the absence of a force. Does not describe zero net force

Also tells us that when no force acts on an object, the acceleration of the object is zero

Can conclude that any isolated object is either at rest or moving at a constant velocity

The First Law also allows the definition of force.

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Inertia and Mass

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Inertia: is the tendency of an object to resist any attempt to change its velocity.

Mass is the measure of inertia.

- Mass is a scalar quantity.
- Mass is a basic quantity.
- The SI unit of mass is kg.

Masses can be defined in terms of the accelerations produced by a given force acting on them:

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$

The magnitude of the acceleration of an object is inversely proportional to its mass.

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Mass vs. Weight

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Mass and weight are two different quantities.

Weight is equal to the magnitude of the gravitational force exerted on the object.

- Weight will vary with location.
- $m_{Earth} = 2\ kg;\ m_{Moon} = 2\ kg$
- $W_{Earth} = 20\ N;\ W_{Moon} \cong 3.3\ N$

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Newton’s Second Law

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

Mathematically,

$$\vec{a} = \frac{\sum \vec{F}}{m} \quad \Leftrightarrow \quad \sum \vec{F} = m\vec{a}$$

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Newton’s Second Law

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$\sum \vec{F}$ is the net force

- This is the vector sum of all the forces acting on the object.
- May also be called the total force, resultant force.
- The SI unit of force is the Newton (N).
- $1\ N = 1\ kg.m/s^2$

Newton’s Second Law can be expressed in terms of components:

- $\sum F_x = ma_x$
- $\sum F_y = ma_y$
- $\sum F_z = ma_z$

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Newton's Third Law

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"If two objects interact, the force $\vec{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{F}_{21}$ exerted by object 2 on object 1."

Mathematically:

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

- Note on notation: $\vec{F}_{AB}$ is the force exerted *by* A *on* B.
- One of the forces is the action force, the other is the reaction force.
- It doesn't matter which is considered the action and which the reaction.

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Action-Reaction

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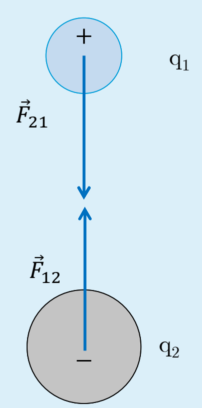
The force $\vec{F}_{12}$ exerted by charge 1 on charge 2 is equal in magnitude and opposite in direction to $\vec{F}_{21}$ exerted by charge 2 on charge 1.

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



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Action-Reaction

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The action and reaction forces are:

- of the same magnitude
- in opposite directions
- acting on different objects
- of the same type.

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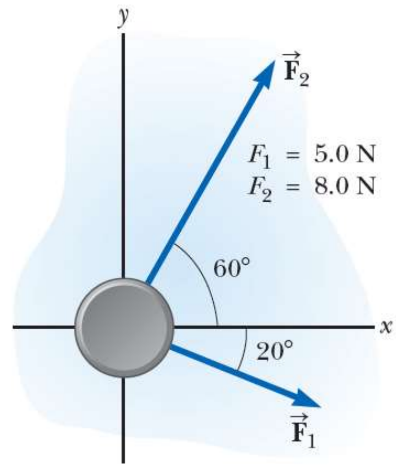
An Accelerating Hockey Puck

Friday, 29 January, 2021 21:33

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

A hockey puck having a mass of (0.3 kg) slides on the frictionless, horizontal surface of an ice rink. Two hockey sticks strike the puck simultaneously, exerting the forces on the puck shown. The force $\vec{F}_1$ has a magnitude of (5 N), and the force $\vec{F}_2$ has a magnitude of (8 N). Determine both the magnitude and the direction of the puck's acceleration.



SOLUTION

Find the component of the net force acting on the puck in the x direction:

$$\sum F_x = F_{1x} + F_{2x} = F_1 \cos -20° + F_2 \cos 6\,0°$$

$$= 5.0N\ 0.940 + 8.0N\ 0.500 = 8.7N$$

Find the component of the net force acting on the puck in the y direction:

$\sum_2 sin\ 6$

$$\sum F_y = F_{1y} + F_{2y} = F_1 sin$$

$$= 5.0N\ -0342 + 8.0N\ 0.866 = 5.2N.$$

Use Newton's second law to find the x and y components of the puck's acceleration:

$$a_x = \frac{\sum F_x}{m} = \frac{8.7N}{0.30kg} = 29m/s^2$$

$$a_y = \frac{\sum F_y}{m} = \frac{5.2N}{0.30kg} = 17m/s^2$$

Find the magnitude of the acceleration:

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

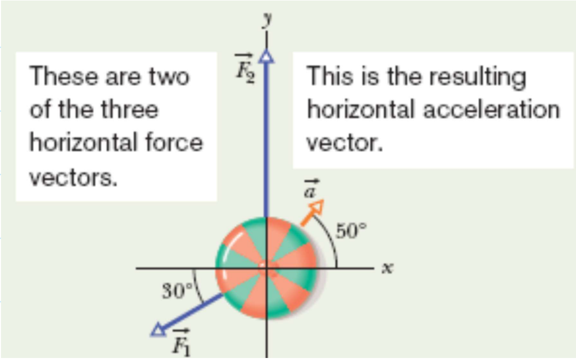
Find the direction of the acceleration relative to the positive x axis:

$$\theta = tan^{-1}\left(\frac{a_y}{a_x}\right) = tan^{-1}\left(\frac{17}{29}\right) = 31°$$

An Accelerating cookie tin

Friday, 29 January, 2021 21:33

In the overhead view of the figure, a 2.0 kg cookie tin is accelerated at 3.0 m/s^2 in the direction shown by $\vec{a}$, over a frictionless horizontal surface. The acceleration is caused by three horizontal forces, only two of which are shown: $\vec{F}_1$ of magnitude 10 N and $\vec{F}_2$ of magnitude 20 N. What is the third force $\vec{F}_3$ in unit-vector notation and in magnitude-angle notation?



SOLUTION

The net force $\vec{F}_{net}$ on the tin is the sum of the three forces

$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = m\vec{a},$

Which gives us

$\vec{F}_3 = m\vec{a} - \vec{F}_1 - \vec{F}_2.$

X components:

$$F_{3,x} = ma_x - F_{1,x} - F_{2,x} = m(a\cos 50°) - F_1 \cos(-150°) - F_2 \cos 90° \Rightarrow F_{3,x} = (2.0kg)(3.0m/s^2)\cos 50° - (10N)\cos(-150°) - (20N)\cos 90° = 12.5N$$

y components:

$$F_{3,y} = ma_y - F_{1,y} - F_{2,y} = m(a\sin 50°) - F_1 \sin(-150°) - F_2 \sin 90°$$

$$\Rightarrow F_{3,x} = (2.0kg)(3.0m/s^2)\sin 50° - (10N)\sin(-150°) - (20N)\sin 90° = -10.4N$$

In unit-vector notation, we can write:

$$\vec{F}_3 = F_{3,x}\hat{\imath} + F_{3,y}\hat{\jmath} = (12.5N)\hat{\imath} - (10.4N)\hat{\jmath}$$

The magnitude and the angle are:

$$F_3 = \sqrt{F_{3,x}^2 + F_{3,y}^2} = \sqrt{12.5^2 + (-10.4)^2} = 16.3N$$

$$\theta = tan^{-1}\frac{F_{3,y}}{F_{3,x}} = tan^{-1}\frac{-10.4}{12.5} = -40°$$