Introduction to Mechanics
Dynamics
Forces
Newton's Laws

Lana Sheridan

De Anza College

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Last time

- forces
- net force
- equilibrium
- free body diagrams
- Newton's first law
- inertia

Overview

- Newton's second law
- mass and weight
- Newton's second law and kinematics
- vector addition with forces

Newton's Second Law

Galileo also proposed the concept of acceleration, but Newton realized:

$$\text{acceleration} \propto \text{net Force}$$

(Remember net force is the sum of all the forces on an object)

If the net force on an object is doubled, the acceleration is twice as big also.

Newton's Second Law

Newton II

In an inertial reference frame, the sum of the forces (net force) on an object is equal to the mass of the object times its acceleration:

$$\vec{\mathbf{F}}_{\text{net}} = m\vec{\mathbf{a}}$$

$\vec{\mathbf{F}}_{\text{net}} = \sum_i \vec{\mathbf{F}}_i$ where $\vec{\mathbf{F}}_i$ are individual separate forces that we sum to get the net force.

(We are assuming the mass of the object is constant.)

Units of Force

Newton's second law gives us units for force.

$$\begin{aligned} F_{\text{net}} &= ma \\ \text{Newtons, N} &= (\text{kg})\ (\text{ms}^{-2}) \end{aligned}$$

$1\text{N} = 1$ kg m s^{-2}: on Earth's surface there are roughly 10 N per kg. Why?

Mass vs. Weight

mass, m

A measure of the amount of matter in an object. Also, a measure of the inertia of an object, that is, its resistance to changes in its motion. (SI unit: kg.)

weight, F_g

The force due to gravity on an object. (SI unit: N.)

Weight is a force.

Mass and Inertia

Mass is also a measure of resistance to acceleration.

For a constant net applied force:

$$\text{acceleration} \propto \frac{1}{\text{mass}}$$

The mass, m, in the equation $\vec{\mathbf{F}}_{\text{net}} = m\vec{\mathbf{a}}$ is sometimes called "inertial mass".

Weight and acceleration

Let the **weight** of an object be written F_g. Then,

$$F_g = mg$$

Mass in this equation is sometimes called "gravitional mass".

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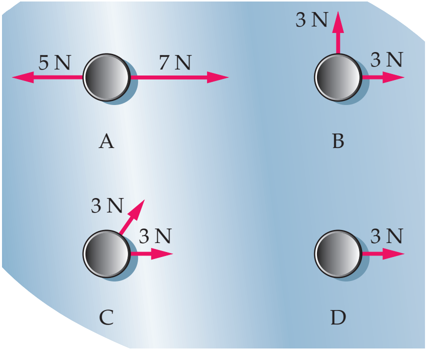
$$a = \frac{F_g}{m} = \frac{mg}{m} = g$$

As we would expect! This is because the inertial mass is the same as the gravitational mass.

That is why all objects, no matter their mass, fall at the same rate (with the same acceleration).

Question

A hockey puck is acted on by one or more forces, as shown. Rank the four cases, A, B, C, and D, in order of the magnitude of the puck's acceleration, starting with the smallest. Ties are shown in brackets.



A A, B, C, D

B D, C, C, A

C A, D, B, C

D D, (B and C), A

[1]Walker, "Physics", page .

Question

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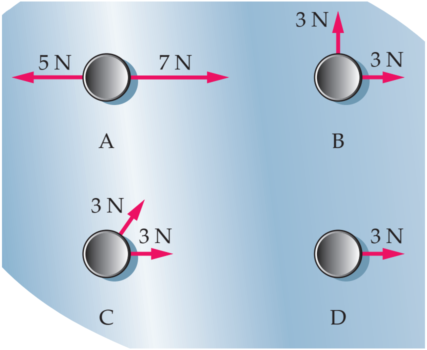

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Newton's Second Law Implications

Question. If an object is not accelerating, can there be forces acting on it?

A Yes.

B No.

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A Yes. ←

B No.

Force Diagrams, Newton's Second Law, and Kinematics

An astronaut uses a jet pack to push on a 655-kg satellite. If the satellite starts at rest and moves 0.675 m after 5.00 seconds of pushing, what is the force, $\vec{\mathbf{F}}$, exerted on it by the astronaut?

(a) Physical picture

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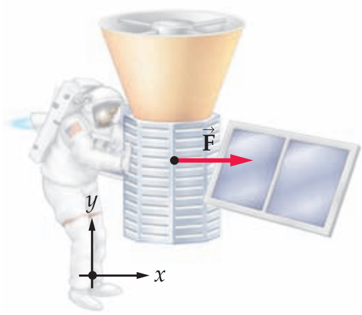
Sketch:



(b) Free-body diagram

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Hypothesis: The satellite is very massive. Its not moving very far very fast, but it is accelerating. Guess: maybe $F = 30$ N, directed in the positive x-direction.

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Given: $\boldsymbol{\Delta x}$, t, m
Want: $\vec{\mathbf{F}}$

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Want: $\vec{\mathbf{F}}$

Strategy: to find the force we must find the acceleration.

$$\Delta x = v_{0x}t + \frac{1}{2}a_x t^2$$

Force Diagrams, Newton's Second Law, and Kinematics

$$\Delta x = \cancelto{0}{v_{0x} t} + \frac{1}{2} a_x t^2$$

$$a_x = \frac{2(\Delta x)}{t^2}$$

$$a_x = 0.0540 \text{ m/s}^2$$

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Newton's second law (x-component):

$$F_{\text{net},x} = ma_x F_x = ma$$

$$F_x = 35.4 \text{ N}$$

$$\underline{\vec{\mathbf{F}} = 35.4 \text{ N } \hat{\mathbf{i}}}$$

Force Diagrams, Newton's Second Law, and Kinematics

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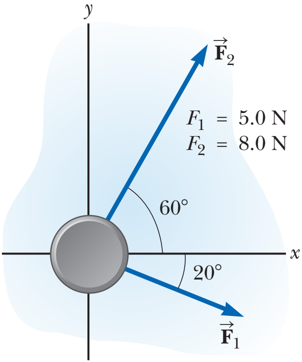
Reasonable: Hypothesis was a ballpark guess, but this is very close! Seems reasonable.

Example

Consider two forces on a 0.3 kg hockey puck on frictionless ice. Find the components of its net force and the magnitude and direction of its acceleration.



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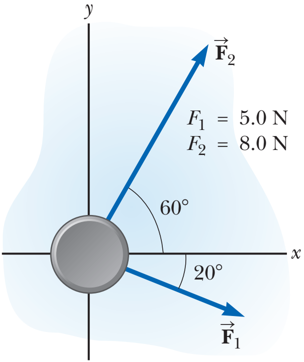

$$
\begin{aligned}
\vec{\mathbf{F}}_{\text{net}} &= \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 \\
&= (F_1 \cos(20)\,\hat{\mathbf{i}} - F_1 \sin(20)\,\hat{\mathbf{j}}) \\
&\quad +(F_2 \cos(60)\,\hat{\mathbf{i}} + F_2 \sin(60)\,\hat{\mathbf{j}}) \\
&= 8.70\,\hat{\mathbf{i}} + 5.21\,\hat{\mathbf{j}} \text{ N}
\end{aligned}
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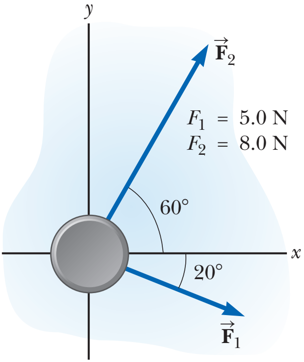

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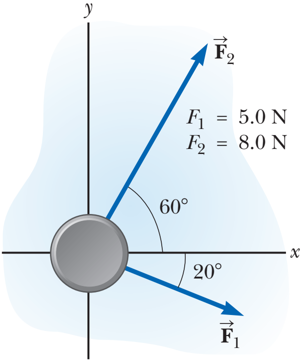
\end{aligned}
$$

$$
\begin{aligned}
\vec{\mathbf{a}} &= \frac{\vec{\mathbf{F}}_{\text{net}}}{m} \\
&= \frac{8.70\ \text{N}\,\hat{\mathbf{i}} + 5.21\ \text{N}\,\hat{\mathbf{j}}}{0.3\ \text{kg}} \\
&= 29.0\,\hat{\mathbf{i}} + 17.4\,\hat{\mathbf{j}}\ \text{ms}^{-2}
\end{aligned}
$$

Example

Consider two forces on a 0.3 kg hockey puck on frictionless ice. Find the components of its net force and the magnitude and direction of its acceleration.



$$\vec{\mathbf{a}} \;=\; 29.0\,\hat{\mathbf{i}} + 17.4\,\hat{\mathbf{j}}\ \text{ms}^{-2}$$

$$a = \sqrt{29.0^2 + 17.4^2} = 34\ \text{ms}^{-2}$$

at an angle

$$\theta = \tan^{-1}\left(\frac{17.4}{29.0}\right) = 31^\circ$$

above the horizontal (x-axis).

Summary

- Newton's second law
- mass and weight
- Newton's second law and kinematics
- vector addition with forces

Homework

Walker Physics:

- Ch 5, onward from page 138. Questions: 1, 3, 5, 13, 23; Problems: 1, 3, 5, 11, 33