

Conceptual Physics I

Classical Mechanics

Lesson 4A - Newton's Second Law

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We notice from our “real-world” experiences the following things:

- 1) In order to get an object moving (accelerating), you have to apply a force to it.

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We notice from our “real-world” experiences the following things:

- 2) The bigger the force you apply, the bigger the acceleration. Actually, if you double the force, the acceleration doubles; triple the force, the acceleration triples. *acceleration ~ net force* (“acceleration is directly proportional to the net force”)

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We notice from our “real-world” experiences the following things:

3) Acceleration depends on how big the mass being pushed. Double the mass, and the same force only achieves half the acceleration. Acceleration $\sim \frac{1}{mass}$ (“acceleration is inversely proportional to the mass”)

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Combining these observations about the relationships among force, acceleration and mass, Newton came up with one of the most important rules of nature, the Newton's Second Law:

The acceleration produced by a net force on an object is directly proportional to the magnitude of the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.

$$\text{acceleration} \sim \frac{\text{net force}}{\text{mass}}$$

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Let's take a look at these units. If we rewrote Newton's Second Law as the more familiar

$$F = ma$$

and analyzed the units, we could readily see that

$$1 \text{ Newton} = 1 \text{ kg} \times 1 \text{ m/s}^2 = 1 \text{ kg} \cdot \text{m/s}^2$$

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Examples using Newton's Second Law

1) How much force (thrust) must a 30,000-kg jet plane develop to an acceleration of 1.5 m/s^2 ?

$$F = (30,000 \text{ kg})(1.5 \text{ m/s}^2) = 45,000 \text{ kg}\cdot\text{m/s}^2 = 45,000 \text{ N}$$

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Examples using Newton's Second Law

2) What acceleration is produced by a force of 2000 N applied to a 1000-kg car?

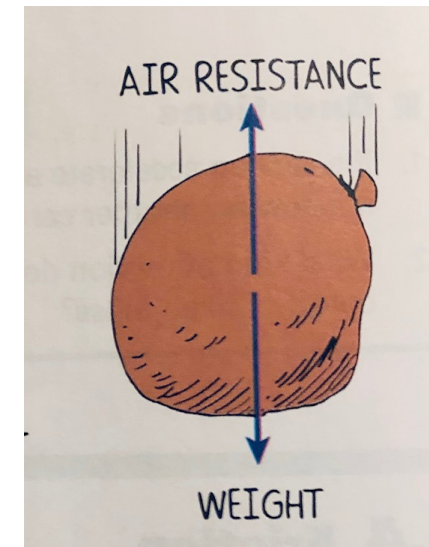
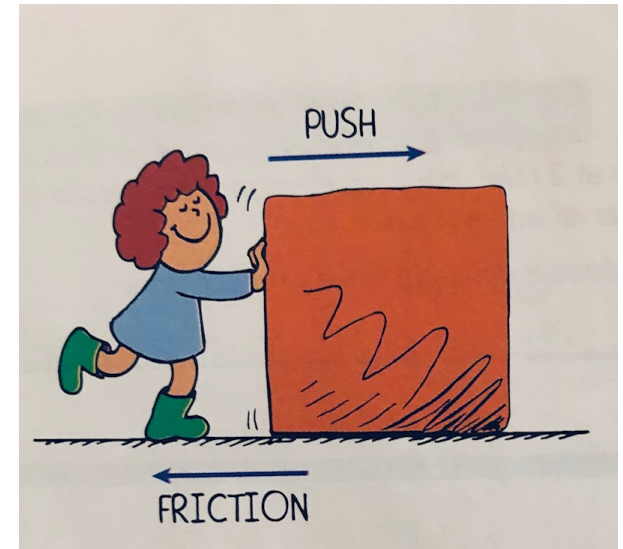
$$a = F/m = 2000 \text{ N}/1000 \text{ kg} = 2 \text{ m/s}^2$$

What happens if you double the force? Doubles the acceleration to 4 m/s^2

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Friction

- Friction is a force like any other force and affects motion.
- Friction acts on materials that are in contact with each other
- Friction always acts in a direction to oppose motion (slows objects down)
- There are different types of material states that experience friction: solid-on-solid, fluids, and objects moving through air.



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Friction

- When friction is present, an object may move with a constant velocity even when a force is acting on it. In such a case, the frictional force just balances the applied force.

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Questions:

- 1) Two forces act on a book resting on a table: its weight and the support force from the table. Does a force of friction act as well? **No. The friction won't act unless there is another force trying to make the book move to the side.**
- 2) Suppose a high-flying jet cruises with a constant velocity when the thrust from its engines is a constant 80,000 N. What is the acceleration of the jet? **Zero.** What is the force of air resistance acting on the jet? **80,000 N in the direction opposite to the motion.**

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Review Questions:

- 1) State Newton's Second Law in words and then in the form of an equation. The acceleration of an object is directly proportional to and in the same direction as the net force and inversely proportional to the object's mass.

$$a = F/m \quad \text{or} \quad F = ma$$

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Review Questions:

2) What do “directly proportional” and “inversely proportional” mean? “Directly proportional” means as one quantity increases, another quantity increases as well by the same factor. “Inversely proportional means as one quantity increases, another quantity decreases by the same factor.

3) How much force does a 20,000 kg rocket develop to accelerate 1 m/s^2 ? 20,000 N

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Review Questions:

- 4) What is the cause of friction, and in what direction does it act with respect to the motion of a sliding object? **Friction is caused by the bumping together of uneven surfaces. It acts opposite to the motion.**
- 5) If the force of friction acting on a sliding crate is 100 N, how much force must be applied to maintain a constant velocity? **100 N** What will be the net force acting on the crate? **Zero** What will be the acceleration? **Zero**

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Review Questions:

- 6) Calculate the acceleration of a 2000-kg, single-engine airplane just before takeoff, when the thrust of its engine is 500 N. $500 \text{ N} / 2000 \text{ kg} = 0.25 \text{ m/s}^2$
- 7) Calculate the acceleration if you push with a 20-N horizontal force on a 2-kg block on a horizontal friction-free air table. $20 \text{ N} / 2 \text{ kg} = 10 \text{ m/s}^2$

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Review Questions:

- 8) Calculate the horizontal force that must be applied to a 1-kg puck to make it accelerate on a horizontal friction-free air table with the same acceleration it would have if it were dropped and fell freely.

$$(1 \text{ kg})(9.8 \text{ m/s}^2) = 9.8 \text{ N}$$

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Review Questions:

- 9) What is the difference between saying that one quantity is proportional to another and saying it is equal to another? There is always a “constant of proportionality” relating two quantities that are proportional to each other. For example, net force is directly proportional to acceleration, but not equal to it. The constant of proportionality is the mass.

$$F \sim a \quad F = ma$$

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Review Questions:

10) A rocket fired from its launching pad not only picks up speed, but its acceleration also increases significantly as firing continues. Why is this so? About 90% of the mass of a newly launched rocket is fuel. The mass is continually decreasing, so the acceleration will continually increase.

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Review Questions:

- 11) If you push horizontally on your book with a force of 1 N to make the book slide at constant velocity, how much is the force of friction on the book?
1 N against the motion
- 12) If a 1-N net force accelerates a 1-kg mass at 1 m/s^2 , what is the acceleration caused by a net force of 2 N on a 2-kg mass? **1 m/s^2**

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Review Questions:

13) What is the acceleration of a 747 jumbo jet, mass 30,000 kg, in takeoff when the thrust for each of its four engines is 30,000 N?

$$4(30,000 \text{ N})/30,000 \text{ kg} = 4 \text{ m/s}^2$$