Newton's Second Law

Unit: Dynamics (Forces) & Gravitation

NGSS Standards: HS-PS2-1

MA Curriculum Frameworks (2006): 1.4

AP Physics 1 Learning Objectives: 1.C.1.1, 2.B.1.1, 3.A.2.1, 3.B.1.1, 3.B.1.3, 4.A.2.1, 4.A.3.1, 4.A.3.2

Skills:

- Solve problems relating to Newton's Second Law ($F = ma$)
- Solve problems that combine kinematics (motion) and forces

Language Objectives:

- Identify and correctly use the quantities involved in a Newton's Second Law problem.
- Identify and correctly use the quantities involved in a problem that combines kinematics and forces.

Labs, Activities & Demonstrations:

- Handstands in an elevator.

Notes:

Newton's Second Law: Forces cause acceleration (a change in velocity). "A net force, $\vec{F}$, acting on an object causes the object to accelerate in the direction of the net force."

If there is a net force, the object accelerates (its velocity changes). If there is no net force, the object's velocity remains the same.

If an object accelerates (its velocity changes), there was a net force on it. If an object's velocity remains the same, there was no net force on it.

Remember that forces are vectors. No net force can either mean that there are no forces at all, or it can mean that there are equal forces in opposite directions and their effects cancel.

Use this space for summary and/or additional notes:

In equation form:

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

This form is preferred, because acceleration is what results from a force applied to a mass. (*I.e.,* force and mass are the independent variables and acceleration is the dependent variable. Forces cause acceleration, not the other way around.) However, the equation is more commonly written:

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

Sample Problems

Most of the physics problems involving forces require the application of Newton's Second Law, $\vec{a} = \frac{\vec{F}_{net}}{m}$.

Q: A net force of 50 N in the positive direction is applied to a cart that has a mass of 35 kg. How fast does the cart accelerate?

A: Applying Newton's Second Law:

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

$$\vec{a} = \frac{50}{35}$$

$$\vec{a} = 1.43\ \tfrac{\text{m}}{\text{s}^2}$$

Q: What is the weight of (*i.e.,* the force of gravity acting on) a 10 kg block?

A: $\vec{a} = \vec{g}$

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

$\vec{F}_g = (10.)(10) = 100\ \text{N}$

(Remember that we use the variable $\vec{g}$ instead of $\vec{a}$ when the acceleration is caused by a gravity field.)

Use this space for summary and/or additional notes.

Free Body Diagrams and Newton's Second Law

Free-body diagrams are often used in combination with Newton's second law ($\vec{a} = \frac{\vec{F}_{net}}{m}$); the free-body diagram enables you to calculate the net force, from which you can calculate mass or acceleration.

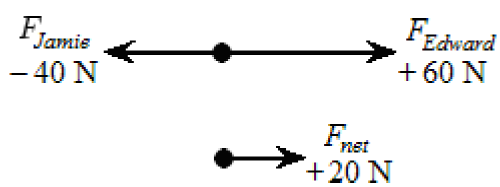
Sample Problem:

Q: Two children are fighting over a toy.

Jamie pulls to the left with a force of 40 N, and Edward pulls to the right with a force of 60 N. If the toy has a mass of 0.6 kg, what is the resulting acceleration of the toy?

A: Let us decide that the positive direction is to the right. (This is convenient because the force to the right is larger, which means the net force will come out to a positive number.)

The force diagram looks like this:



$$\vec{a} = \frac{\vec{F}_{net}}{m} = \frac{+20}{0.6} = +33.3\,\tfrac{m}{s^2}\ \text{(to the right)}$$

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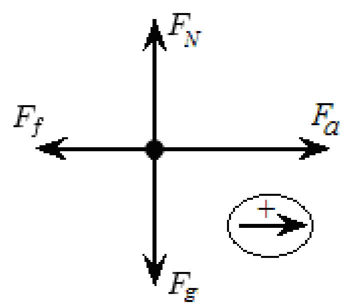
Q: A 5.0 kg block is resting on a horizontal, flat surface. How much force is needed to overcome a force of 2.0 N of friction and accelerate the block from rest to a velocity of $6.0\,\frac{m}{s}$ over a 1.5-second interval?

A: This is a combination of a Newton's second law problem, and a motion problem. We will need a free-body diagram to be able to visualize what's going on.

The free-body diagram for the block looks like this:



3. The net force is given by:

$$F_{net} = F_a - F_f = F_a - 2$$
$$F_a = F_{net} + 2$$

This means we need to find the net force, and then add 2 N to get the applied force.

4. To find the net force, we need the equation:

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

5. We know that *m* = 5.0 kg, but we don't know *a*. We need to find *a* in order to calculate F_{net}. For this, we will turn to the motion problem.

6. The problem tells us that $v_o = 0$, $v = 6.0\,\frac{m}{s}$, and $t = 1.5\text{ s}$. Looking at the motion equations, we see that we have all of the variables except for *a* in the equation:

$$v - v_o = at$$

Use this space for summary and/or additional notes.

3. Our strategy is to solve this equation for a, then substitute into $F_{net}=ma$ to find F_{net}, then use the relationship we found from the free-body diagram to find F_a.

   The acceleration is:

$$v-v_o=at$$
$$6.0-0=a(1.5)$$
$$6.0=1.5a$$
$$a=4.0\,\tfrac{\text{m}}{\text{s}^2}$$

   Substituting back into $F_{net}=ma$ gives:

$$F_{net}=ma$$
$$F_{net}=(5.0)(4.0)$$
$$F_{net}=20.\,\text{N}$$

   Finally:

$$F_a=F_{net}+2$$
$$F_a=20+2$$
$$F_a=22\,\text{N}$$

Problems like this are straightforward to solve, but they are challenging because you need to keep chasing the quantities that you don't know until you have enough information to calculate them. However, you need to keep track of each step, because once you have found the last equation you need, you have to follow the steps in reverse order to get back to the answer.

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Homework Problems

1. Two horizontal forces, 225 N and 165 N are exerted on a canoe. If these forces are both applied eastward, what is the net force on the canoe?

2. Two horizontal forces are exerted on a canoe, 225 N westward and 165 N eastward. What is the net force on the canoe?

Questions 3 & 4 refer to the following situation:

Three confused sled dogs are trying to pull a sled across the snow in Alaska. Alutia pulls to the east with a force of 135N. Seward pulls to the east with a force of 142N. Kodiak pulls to the west with a force of 153N.

3. What is the net force on the sled?

   Answer: 124 N east

4. If the sled has a mass of 150. kg and the driver has a mass of 100. kg, what is the acceleration of the sled? (Assume there is no friction between the runners of the sled and the snow.)

   Answer: $0.496\,\frac{m}{s^2}$

Use this space for summary and/or additional notes.

5. When a net force of 10.N acts on a hockey puck, the puck accelerates at a rate of $50.\frac{m}{s^2}$. Determine the mass of the puck.

   Answer: 0.20 kg

6. A 15N net force is applied for 6.0 s to a 12 kg box initially at rest. What is the speed of the box at the end of the 6.0 s interval?

   Answer: $7.5\frac{m}{s}$

7. An 810 kg car accelerates from rest to $27\frac{m}{s}$ in a distance of 120m. What is the magnitude of the average net force acting on the car?

   Answer: 2 460 N

8. A 44 kg child places one foot on each of two scales side-by-side. What is the child's weight? If the child distributes equal amounts of weight between the two scales, what is the reading on each scale? (Assume the scales display weights in newtons.)

Use this space for summary and/or additional notes.

9. A 70.0 kg astronaut pushes on a spacecraft with a force $\vec{F}$ in space. The spacecraft has a total mass of 1.0×10^4 kg. During the push, the astronaut accelerates to the right with an acceleration of $0.36\frac{m}{s^2}$. Determine the magnitude of the acceleration of the spacecraft.

   Answer: $0.0025\ \frac{m}{s^2}$

10. How much force will it take to accelerate a 60 kg student, wearing special frictionless roller skates, across the ground from rest to $16\frac{m}{s}$ in 4 s?

    Answer: 240 N

11. How much force will it take to accelerate a student with mass *m*, wearing special frictionless roller skates, across the ground from rest to velocity *v* in time *t*? (You may use your work from problem #10 above to guide your algebra.)

    Answer: $F=\frac{mv}{t}$

Use this space for summary and/or additional notes.

12. How much force would it take to accelerate a 60 kg student upwards at $2\frac{m}{s^2}$?

Answer: 720 N

13. How much will a 400 N air conditioner weigh on the planet Mercury, where the value of g is only $3.6\frac{m}{s^2}$?

Answer: 146.9N

14. A person pushes a 500 kg crate with a force of 1200 N and the crate accelerates at $0.5\frac{m}{s^2}$. What is the force of friction acting on the crate?

Answer: 950N

Use this space for summary and/or additional notes.