Forces
Newton’s Second Law of Motion

CONCEPT EXPLORATION

In the last lesson, we learned how objects behave when the forces that act on them are in balance.
What would happen to you if one of your “friends” exerted a large unbalanced force on your body? If we shot students out of a cannon, would a student go farther if we used more gunpowder? Would a big student go as far as a smaller student?
In this lesson we will investigate unbalanced forces and how they affect the motion of the objects that they act upon.

The photograph below illustrates two cars in a drag race.

Engagement Questions

1. Would the power of the engine in each dragster be a factor in who wins the race? Explain your answer.

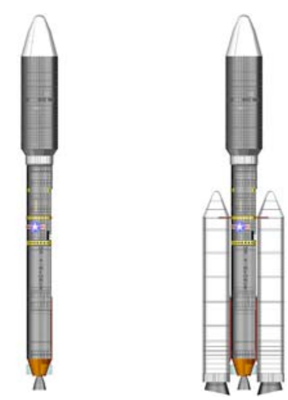
2. Why do the engineers who design racecars remove the seats and any excess metal from the body of the racecar?

The Challenge

You will determine how the amount of acceleration that a body experiences is affected by the size of the unbalanced force that acts on the body.

Your Ideas about the Challenge

Scientists have two different rockets that they can use to send payloads into space. One of the rockets has a single engine while the other one is identical except that it also has two booster rockets.

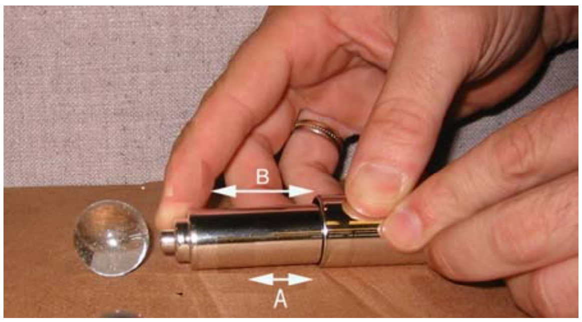


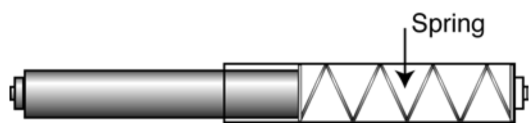
3. Which rocket do you think will have the greater acceleration on liftoff? Explain your answer.

At each lab station you will find the following materials:
a device that can deliver a variety of reproducible forces and a marble.

The Investigation
a. Using a pen or felt tip marker, place a mark on the side of the inner cylinder two cm away from the end of the outer cylinder. Place another mark that is 4 cm away from the end of the outer cylinder.
b. Compress the inner cylinder so that the 2-cm mark lines up with the end of the outer cylinder. Release the inner cylinder so that it snaps back into its original position.
c. Compress the inner cylinder so that the 4-cm mark lines up with the end of the outer cylinder. Release the inner cylinder, again, so that it snaps back into its original position.

4. Was it easier or harder to compress the spring inside the reproducible-force device through a greater distance?





The photo above illustrates the reproducible-force device (toilet paper roller).

Suppose you were going to use the device to shoot the marble shown in the photo.
You can compress the inner cylinder either through distance A or B before placing the end of the inner cylinder against the marble.
You would then release the inner cylinder and "shoot" the marble.

5. Would the marble experience a greater change in velocity if the inner cylinder was compressed through distance A or distance B? Why?

The Investigation
a. Compress the reproducible-force device to the 2-cm mark on the inner cylinder. Hold the end of the cylinder against the marble. Let the inner cylinder snap outwards so that you "shoot" the marble along the table top.
b. Repeat step "a" after compressing the inner cylinder of the reproducible-force device to the 4-cm mark.

6. When did the marble seem to gain the greatest velocity, when you used the 2-cm compression or when you used the 4-cm compression of the reproducible-force device. How do you explain this?

7. What do you think causes a greater change in velocity for a given object, a big force or a small force?

8. What is the relationship between acceleration and the applied force on a given body? Is this a direct proportion or is this an inverse proportion? Explain how you know.

9. Evaluate the following student statements about the investigation that you just performed. Indicate which student you agree with and which student you disagree with and why.

Student A
"I think that the size of the force on an object doesn't matter. If I barely kick a volleyball it will go a long ways. If I kick a bowling ball as hard as I can, it doesn't hardly move."

Student B
"You're crazy! You applied two different forces to two different objects. If you kicked the volleyball as hard as you could it would go a lot farther than if you barely kicked it."

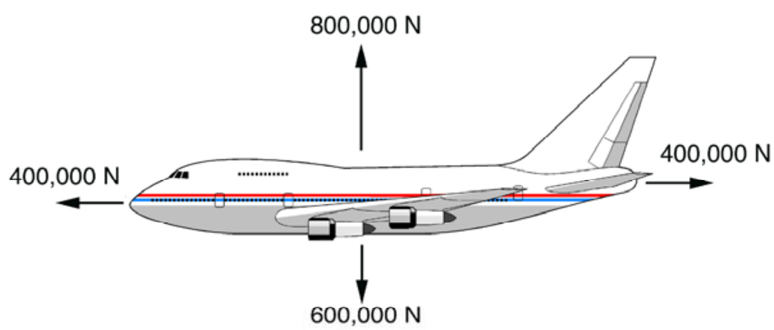
Part of Isaac Newton's 2nd law states that the acceleration experienced by a given object is directly proportional to the unbalanced force that the object receives. This can be expressed mathematically in the following way:

$$a \propto F_{net}$$

When we talk about unbalanced forces we typically express this concept as the net force (F_{net}). "Net force" takes into consideration that there may be lots of forces acting on an object in the same or opposite direction. By **net force**, we really mean the vector sum of the forces in a particular direction. The directions that we usually deal with are either horizontal or vertical.

Net force can also be expressed as ΣF. The Greek symbol Σ (sigma) mean "the sum of" in mathematics. When we refer to ΣF we are reminding you that you need to "add" up all of the forces in the direction of motion, including any components of forces that act along that direction.

10. What is the net force (F_{net}) acting on the jet, pictured to the right, in the horizontal direction?



11. What kind of horizontal acceleration would this jet experience?

12. What is the net force (F_{net}) acting on the jet, pictured to the right, in the vertical direction?

13. Would this jet accelerate up or down?

Check your work with your teacher.

At each lab station you will find the following materials:
a reproducible-force device, a marble, and a ball bearing.

The Investigation (Continued)

a. Compress the reproducible-force device to the 2-cm position.
b. Hold the end of the inner cylinder against the marble and let the inner cylinder "snap" back to its original position so that you shoot the marble along the table top.
c. Repeat steps "a" and "b" with the ball bearing making sure that it receives the same amount of force as the marble.

14. Which object, the marble or the ball bearing, has greater inertia? How do you know?

The reproducible-force device was used to produce the same force on each object.

15. Which of the two spheres experienced the greater change in velocity? Why do you think that this happened?

Another part of Newton's 2nd law involves the relationship between the mass (or inertia) of an object and the acceleration that it would experience from a given force. This is an inverse proportion and it can be expressed in the following way:

$$a \propto \frac{1}{m}$$

An athlete throws two different shotputs. One of the shotputs has a mass of 3 kg and the other one has a mass of 6 kg.

16. If the athlete uses the same amount of force on each of these shotputs, which one will go the farthest? Explain your answer.

Check your work with your teacher.

Forces Newton's Second Law of Motion

CONCEPT DEVELOPMENT

In the exploration activity you learned that the acceleration, than an object experiences, is directly proportional to the net force the object receives and that it is inversely proportional to the mass of the object.
In the following lesson you will learn how to calculate the force that makes you fall. If you jump off of a diving board, what force acts on you causing you to accelerate to the water below?

Engagement Questions

The picture to the right shows a diver who has just hit the peak of their rise as they come off of a diving board.

1. On the diagram, draw and label the force(s) that act on the diver at this moment. Ignore air resistance.

2. Are the forces that act on this diver in balance? Explain how you know.

3. How would you describe the motion of this diver? Is he moving with a uniform velocity or is his velocity changing? Explain your answer.

Newton's 2nd law states that the acceleration of a body is directly proportional to the net force that acts on the body ($a \propto F_{net}$) and the acceleration of the body is inversely proportional to the mass of the body ($a \propto \frac{1}{m}$). If you put these two concepts together you get:

$$a \propto \frac{F_{net}}{m}$$

If you use metric units there is no constant of proportionality and this proportion becomes the equation:

$a = \frac{F_{net}}{m}$ which can be rearranged in the classic form of this very important equation **F_{net} = ma**.
In the case of the diver, from our engagement question, the net force (F_{net}) is the weight of the diver since this is the only force that acts on him in this situation.

4. What is the acceleration that this diver experiences as a result of his weight acting on his mass?

Newton's 2nd law takes on a special form when we refer to the weight of an object. We get all of the variables of Newton's 2nd law to correspond to a variable in the "weight" equation:

$$\begin{array}{ccc} F_{net} & = & m\,a \\ \downarrow & & \downarrow\;\downarrow \\ w & = & m\,g \end{array}$$

The net force (F_{net}) is the weight (w) and the acceleration is the acceleration of gravity (g). You can use the expression **w = mg** to calculate the weight of any object as long as you know the mass of the object.

5. If the diver from our engagement question has a mass of 75 kg, what would his weight be?

The units that you receive when you calculate weight are mass units (kg) multiplied by acceleration units (m/s^2). You get **$kg \cdot m/s^2$**. A $kg \cdot m/s^2$ has a special name and this unit of force (or weight) is named in honor of Isaac Newton. They are simply referred to as Newtons and the abbreviation is the upper-case letter "N".
One Newton is approximately a quarter-of-a-pound which is approximately the weight of a typical apple.
Therefore an apple has a weight of 1 $kg \cdot m/s^2$ or 1 N.

The Challenge
You will work with the equation ($F_{net} = ma$) that is the mathematical version of Newton's 2nd law.

Your Ideas about the Challenge
A toy car is attached by a thread to a coin hanging over the edge of a table. The car is held in place and when it is released it will begin to move.

6. What could you do to this set up to make the car move at a faster rate?

7. Draw the free-body diagram, on the picture that you see to the right, that represents all of the forces that act on the car when it is moving (before it goes off the end of the table). Be sure to label all of the forces.

8. Show how you would calculate the unbalanced force (net force) acting on the car while it is moving.

9. What kind of motion do you think that the car will experience as a result of the unbalanced force acting on it?

10. Draw the free-body diagram, on the picture that you see to the right, that represents all of the forces that act on the coin when it is moving (and before the car goes off the end of the table). Be sure to label all of the forces in the diagram.

11. Show how you would calculate the unbalanced force (net force) acting on the coin while it is moving.

12. What kind of motion do you think the coin will experience? Why?

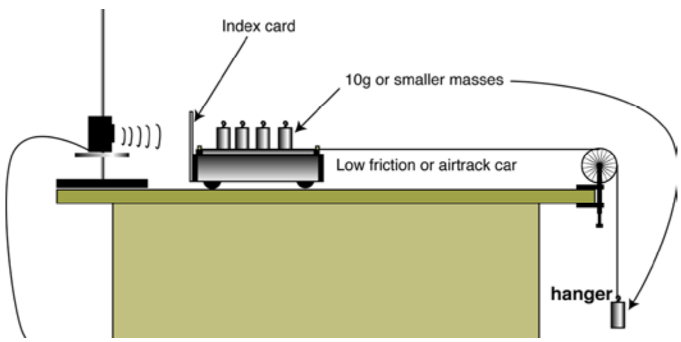
13. Will the motion of the coin differ from the motion of the car? Explain your answer.

Check your work with your teacher.

At each lab station you will find the following materials:
a motion detector along with a computer interface, a low friction cart on a track, an index card, some masking tape, a ring stand, and 5 small masses.

The Investigation

a. Prepare the computer interface and motion detector. Set the motion detector for a sampling rate of 50 Hz.
b. Set up a velocity-time graph on your computer display.
c. Prepare the set up you see illustrated below. You should have just one of the masses hanging from the end of the string and the other 4 riding on the cart. Place the cart 50 cm from the detector (unless your detector is sensitive to 15 cm - then place the cart 15 cm from the detector).
d. Turn on the motion detector.
e. After the motion detector has run for a few seconds, release the cart. Stop the cart just before it strikes the pulley.
f. Turn off the motion detector.
g. If your resulting graphical display is linear, take note of the slope of the velocity-time curve and record this in the data table that follows. If your display is not linear then you will need to repeat steps "c" through "f".
h. Repeat steps "c" through "h" to see if you get roughly the same value for the slope of the velocity-time graph.
i. Move an additional mass to the hanger so that there are now two masses on the hanger and three masses remaining in the car.
j. Repeat c-j with this new set up.
k. Repeat c-j for 3 masses, 4 masses, and finally all 5 masses on the hanger.
l. Find the mass of your entire moving system including the car, all 5 masses, and the string. Record this mass in the data section that follows.



Data

Entire mass of moving system (kg)	

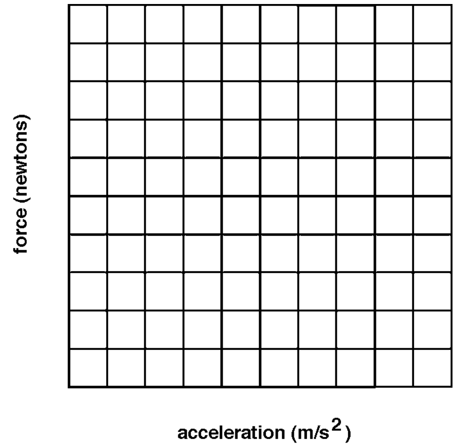
Number of hanging masses	Total mass of hanging masses (kg)	Weight of hanging masses (N)	Slope of velocity-time graph (m/s^2)
1			
2			
3			
4			

5			

14. On the grid you see to the right plot the points that represent the weight of the hanging masses versus the acceleration of the system.

15. Draw a best-fit line that follows the trend of the resulting points on your graph.

16. Is the relationship between force (weight) and acceleration linear?



17. Describe the relationship between the force and the acceleration of the system. Is this a direct or an inverse proportion? Explain how you know.

18. A pair of students in your class have different ideas about the forces that act on object and the resulting changes in velocity. Carefully read the student arguments and decide which statement is best supported by the evidence.

<u>Student A</u>
" The size of an unbalanced force has no affect on the amount of acceleration experienced by an object. All that matters is that the force is unbalanced. If there is an unbalanced force, the object will experience accelerate."

<u>Student B</u>
" The bigger the pull or the push, the bigger the change in motion experienced by an object. There is a linear relationship between the size of the exerted force and the acceleration experienced by an object."

Check your work with your teacher. ☐

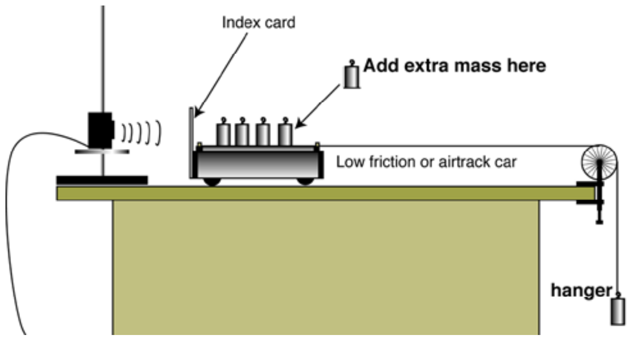
19. Select two non-data points from the resulting best-fit line on your graph. Write these below in coordinate form [(x_1, y_1), (x_2, y_2)].

20. Calculate the slope of your best-fit line by using the two non-data points that you selected in number 19. Be sure to carry through with your units and to label your answer with the appropriate units.

$$\text{slope} = \frac{y_2 - y_1}{x_2 - x_1} =$$

21. What does the slope of your best-fit line correspond to? Hint: you just graphed the equation F_{net} = ma and look at the units that you received for your answer to number 20.

Consider your experimental set up once again. Suppose you were to add mass to the cart, while keeping the weight on the hanger constant.



22. What do you think would happen to the acceleration of the system if you added additional mass? Use Newton's 2nd law to support your response.

Check your work with your teacher.

Forces
Newton's Second Law of Motion

CONCEPT REFINEMENT

Review

In this lesson we examined the relationship between unbalanced or net forces exerted on a system and the resulting acceleration of the system. We found that the acceleration of a system is **directly** proportional to the net force exerted on the system. Another important concept is that the acceleration of a system is **inversely** proportional to the mass of the system. Both of these ideas can be seen in the mathematical form of Newton's 2nd law seen below:

$$a = \frac{F_{net}}{m}$$

The classic form of Newton's 2nd law is the equation shown above solved for net force:

$$\mathbf{F_{net} = ma}$$

The **weight** of an object is a **force** exerted on that object. It is the force of gravity acting on the object. This quantity is calculated using the special form of Newton's 2nd law that is seen below:

$$\mathbf{w = mg}$$

In each of the following problems be sure to show all of your work. Make sure that you carry through with all of the units for each quantity and label each answer with the appropriate units.

A helicopter sits on the flight deck of an aircraft carrier.

1. On the picture provided, draw the free-body diagram for this helicopter as it sits at rest on the flight deck of the aircraft carrier.

2. If this helicopter has a mass of 10,000 kg, what is its weight?

3. Of the forces acting on the helicopter, which, if any, is the biggest? Explain your answer.

4. What is the net force (F_{net}) acting on this helicopter? Explain your answer. Be sure to show how you would "calculate" the net force acting on the helicopter for this situation.

5. What is the acceleration of this helicopter? Explain how you know. Be sure to mention the magnitude of the net force in your answer.

Check your work with your teacher.

The pilot of the helicopter, that is sitting on the flight deck of the aircraft carrier, starts its engines and revs up the engine until it creates an upward thrust, from the spinning blades, equal to 49,000 N.

6. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 49,000 N.

7. Has the helicopter left the ground yet? In other words does it have an upward net force? If not, be sure to show the force of the ground (F_n) continuing to act on this helicopter.

8. What is the net force (F_{net}) acting on this helicopter under these circumstances? Explain your answer. Be sure to show how you would "calculate" the net force acting on the helicopter for this situation.

9. What is the acceleration of this helicopter under these circumstances? Explain how you know. Be sure to mention the magnitude of the net force in your answer.

Check your work with your teacher.

The pilot of the helicopter increases the speed of the engine until the upward thrust is 98,000 N.

10. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 98,000 N.

11. Has the helicopter left the ground yet? In other words does it have an upward net force? If not, what would be the force of the ground (F_n) acting on the helicopter at this moment?

12. What is the net force (F_{net}) acting on this helicopter under these circumstances? Explain your answer. Be sure to show how you would "calculate" the net force acting on the helicopter for this situation.

13. What is the acceleration of this helicopter under these circumstances? Explain how you know. Be sure to mention the magnitude of the net force in your answer.

Check your work with your teacher.

Now the pilot of the helicopter increases the speed of the engine until the upward thrust is 118,000 N.

14. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 118,000 N.

15. Has the helicopter left the ground yet? In other words does it have an upward net force?

16. What is the net force (F_{net}) acting on this helicopter under these circumstances? Explain your answer. Be sure to show how you would "calculate" the net force acting on the helicopter for this situation.

17. What is the acceleration of this helicopter under these circumstances? Use Newton's 2nd law to calculate the acceleration.

Check your work with your teacher.

The pilot of this helicopter maintains the current engine speed, providing an upward thrust of 118,000 N, for 5 seconds.

18. Calculate how high the helicopter would be at the end of 5 seconds.

19. Calculate how fast the helicopter is moving at the end of 5 seconds.

Check your work with your teacher.

The pilot of the helicopter reduces the thrust back to 98,000 N after she had climbed to the altitude you calculated in the previous problem.

20. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 98,000 N once again.

21. What does the helicopter do at this moment? In other words does it have an upward or downward net force? If not, does it stop climbing or does it continue to move upwards? Be sure to include a reference to Newton's 1st law in your explanation.

22. What is the acceleration of this helicopter under these circumstances? Explain how you know the answer to this question.

Check your work with your teacher.

The pilot of the helicopter reduces the thrust, even more, to 78,000 N.

23. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 78,000 N.

24. What does the helicopter do at this moment? In other words does it have an upward or downward net force?

25. What is the net force (F_{net}) acting on this helicopter under these circumstances? Be sure to show how you would "calculate" the net force acting on the helicopter for this situation. Be careful with the signs of the forces. Explain what a negative force indicates.

26. What is the acceleration of this helicopter under these circumstances? Calculate the acceleration using Newton's 2nd law.

27. Calculate how fast the helicopter is moving at the end of this 5-second period.

Check your work with your teacher.

The pilot of the helicopter increases the thrust back to 98,000 N after she had reduced her speed to zero.

28. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 98,000 N once again.

29. What does the helicopter do at this moment? In other words does it have an upward or downward net force? Be sure to include a reference to Newton's 1st law in your explanation.

30. What is the acceleration of this helicopter under these circumstances? Explain how you know the answer to this question.

Check your work with your teacher.

The pilot of the helicopter now tilts the nose of the helicopter down and increases the speed of the engine. By doing this she maintains an upward thrust of 98,000 N and creates a forward thrust of 50,000 N.

31. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 98,000 N and a forward thrust of 50,000 N.

32. What does the helicopter do at this moment? In other words does it have an upward or downward net force? Does it have a forward or backward net force?

33. What is the *vertical* net force (F_{net}) acting on this helicopter under these circumstances? Be sure to show how you would "calculate" the vertical net force acting on the helicopter for this situation.

34. What is the vertical acceleration of this helicopter under these circumstances? Explain how you know the answer to this question.

35. What is the *horizontal* net force (F_{net}) acting on this helicopter under these circumstances? Explain your answer. Include the direction of the horizontal net force in your explanation.

36. What is the horizontal acceleration of this helicopter under these circumstances? Use Newton's 2nd law to calculate the horizontal acceleration. Be sure to include the direction of the acceleration in your answer.

Check your work with your teacher. ☐

The pilot of this helicopter maintains the acceleration, that you calculated in problem 36, for 10 seconds.

37. Calculate how fast the helicopter is moving at the end of 10 seconds.

As the helicopter speeds up the force of air resistance increases. At the end of 10 seconds the amount of air resistance is equal to 20,000 N.

38. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 98,000 N, a forward thrust of 50,000 N, and there is air resistance of 20,000 N.

39. What does the helicopter do at this moment? In other words does it have an upward or downward net force? Does it have a forward or backward net force?

40. What is the *horizontal* net force (F_{net}) acting on this helicopter under these circumstances? Be sure to show how you would "calculate" the horizontal net force acting on the helicopter for this situation and include the direction of the horizontal net force.

41. What is the horizontal acceleration of this helicopter under these circumstances? Use Newton's 2nd law to calculate the horizontal acceleration. Be sure to include whether this acceleration is either forwards or backwards in your answer.

Check your work with your teacher.

Eventually the helicopter is going at a speed where the amount of air resistance is 50,000 N, equal to the forward thrust of the engine. Assume that the upward thrust continues to balance the weight of the helicopter.

42. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 98,000 N, a forward thrust of 50,000 N, and there is air resistance of 50,000 N.

43. What does the helicopter do at this moment? In other words does it have an upward or downward net force? Does it have a forward or backward net force? Be sure to mention Newton's 1st law in your explanation.

44. What is the *vertical* <u>and</u> *horizontal* net force (F_{net}) acting on this helicopter under these circumstances? Are all of the forces in balance?

45. What is the *vertical* <u>and</u> *horizontal* acceleration of this helicopter under these circumstances? Be sure to mention Newton's 1st law in your explanation.

Check your work with your teacher.

The pilot of the helicopter slows the helicopter down as she approaches a cruiser with a helipad on board. She allows the air resistance to slow her down until she is hovering in place over the helipad.

The pilot now cuts her engine so that the upward thrust provided by the engine is only 88,000 N.

46. On the picture provided draw the free-body diagram for this helicopter as its engine provides an upward thrust of 88,000 N.

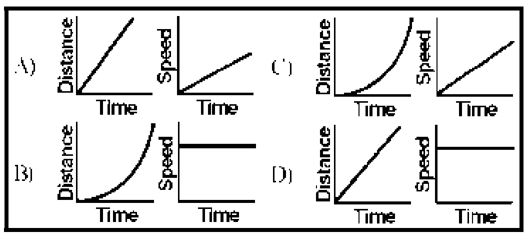
47. What does the helicopter do at this moment? In other words does it have an upward or downward net force?

48. **What is the net force (F_{net}) acting on this helicopter under these circumstances? Be sure to show how you would "calculate" the net force acting on the helicopter for this situation and include the direction of the net force.**

49. **What is the acceleration of this helicopter under these circumstances? Use Newton's 2nd law to calculate the magnitude of the acceleration. Be sure to mention the direction of the acceleration under these circumstances.**

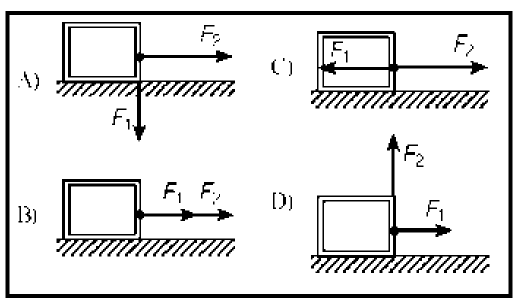
Check your work with your teacher.

50. **Which two graphs represent the motion of an object on which the net force is zero? Explain your reasoning.**



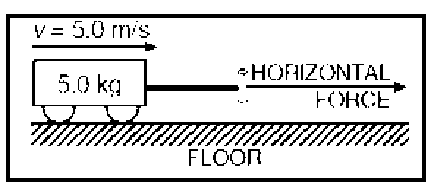
Check your work with your teacher.

51. **A 150 N force, F_1, and a 200 N force, F_2, are applied simultaneously to the same point on a large crate resting on a frictionless-horizontal surface. Which diagram shows the forces directed in such a way as to give the crate the *greatest* acceleration? Explain your reasoning.**



Check your work with your teacher.

A horizontal force is used to pull a 5 kg cart at a constant speed of 5.0 m/s across the floor as shown in the diagram below.



52. **If the force of friction between the cart and the floor is 10 N, what is the magnitude of the horizontal force along the handle of the cart? Explain your reasoning.**

Check your work with your teacher.