Free-Body Diagrams

Unit: Dynamics (Forces) & Gravitation

NGSS Standards: HS-PS2-1

MA Curriculum Frameworks (2006): 1.5

AP Physics 1 Learning Objectives: 3.A.2.1, 3.A.3.1, 3.A.4.3, 3.B.1.1, 3.B.1.2, 3.B.2.1, 4.A.2.2, 4.A.3.2

Skills:

- draw a free-body diagram representing the forces on an object

Language Objectives:

- Understand and correctly use the term "free-body diagram."
- Identify forces by name and draw a free-body diagram.

Labs, Activities & Demonstrations:

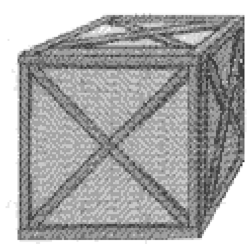
- Human force board activity.

Notes:

free-body diagram (force diagram): a diagram representing the forces acting on an object.

In a free-body diagram, we represent the object as a dot, and each force as an arrow. The direction of the arrow represents the direction of the force, and the relative lengths of the arrows represent the relative magnitudes of the forces.

Consider a box that is at rest on the floor:



The forces on the box are:

- gravity, which is pulling the box toward the center of the Earth
- the normal force from the floor opposing gravity and holding up the box.

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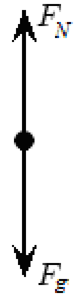
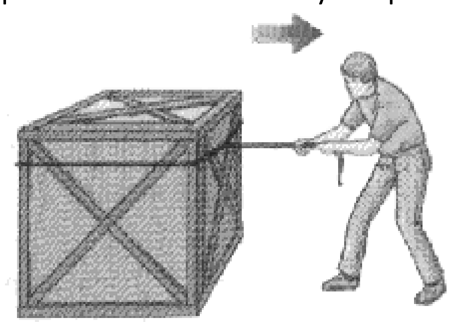
The free-body diagram for the box looks like this:



Now consider the following situation of a box that *accelerates* to the right as it is pulled across the floor by a rope:



From the picture and description, we can assume that:

- The box has weight, which means gravity is pulling down on it.
- The floor is holding up the box.
- The rope is pulling on the box.
- Friction between the box and the floor is resisting the force from the rope.
- Because the box is accelerating to the right, the force applied by the rope must be stronger than the force from friction.

In the free-body diagram, we again represent the object (the box) as a point, and the forces (vectors) as arrows. Because there is a net force, we need to include a legend that shows which direction is positive.

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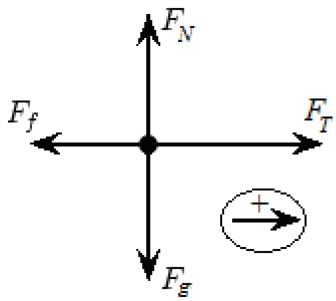

The forces are:

$\vec{F}_g$ = the force of gravity pulling down on the box

$\vec{F}_N$ = the normal force (the floor holding the box up)

$\vec{F}_T$ = the force of tension from the rope. (This might also be designated F_a because it is the force ***applied*** to the object.)

$\vec{F}_f$ = the force of friction resisting the motion of the box.

In the bottom right corner of the diagram, the arrow with the "+" sign shows that we have chosen to make the positive direction to the right.

Notice that the arrows for the normal force and gravity are equal in length, because in this problem, these two forces are equal in magnitude.

Notice that the arrow for friction is shorter than the arrow for tension, because in this problem, the tension is stronger than the force from friction. The difference between the lengths of these two vectors represents the net force, which is what causes the box to accelerate to the right.

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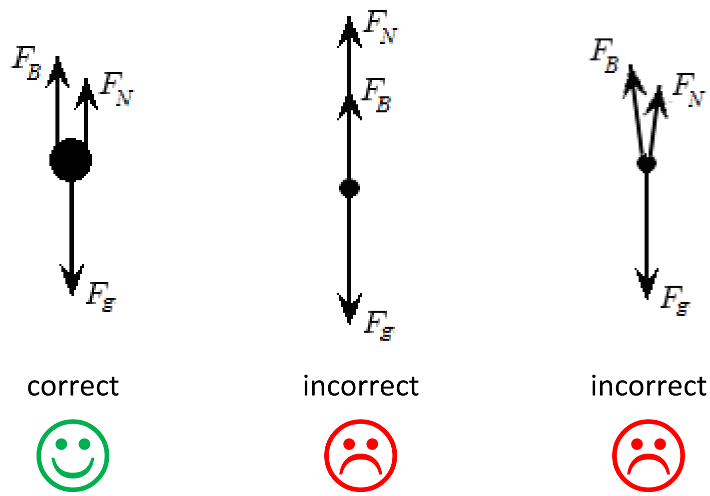
Note that if you have multiple forces in the same direction, each force vector must originate from the point that represents the object, and must be as close as is practical to the *exact* direction of the force.

For example, consider a stationary object with three forces on it: $\boldsymbol{F}_B$ and $\boldsymbol{F}_N$ both acting upwards, and $\boldsymbol{F}_g$ acting downwards.



correct | incorrect | incorrect

The first representation is correct because all forces originate from the point that represents the object, the directions represent the exact directions of the forces, and the length of each is proportional to its strength. Even though the object is represented by a point (which technically has no dimensions), it is acceptable to draw the representation of the point large enough to show each of the forces acting on it.

The second representation is incorrect because it is unclear whether $\boldsymbol{F}_N$ starts from the object (the dot), or from the tip of the arrow representing $\boldsymbol{F}_B$.

The third representation is incorrect because it implies that $\boldsymbol{F}_B$ and $\boldsymbol{F}_N$ each have a slight horizontal component, which is not true.

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Steps for Drawing Free-Body Diagrams

In general, the following are the steps for drawing most free-body diagrams.

1. Is gravity involved?
   - Represent gravity as $\vec{F}_g$ or $m\vec{g}$ pointing straight down.
2. Is something holding the object up?
   - If it is a flat surface, it is the normal force ($\vec{F}_N$ or $\vec{N}$), perpendicular to the surface.
   - If it is a rope, chain, *etc.,* it is the force of tension ($\vec{F}_T$ or $\vec{T}$) acting along the rope, chain, *etc.*
3. Is there an external force pulling or pushing on the object?
4. Is there an opposing force?
   - If there are two surfaces in contact, there is almost always friction ($\vec{F}_f$ or $\vec{f}$), unless the problem specifically states that the surfaces are frictionless.
   - At low velocities, air resistance is very small and can usually be ignored, even if the problem does not explicitly say so.
   - Usually, all sources of friction are shown as one combined force. *E.g.,* if there is sliding friction along the ground and also air resistance, the $\vec{F}_f$ vector includes both.
5. Are forces acting in opposing directions?
   - If the problem requires calculations involving opposing forces, you need to indicate which direction is positive.

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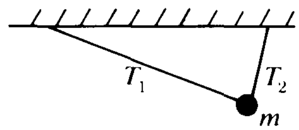
What AP Free-Body Diagram Problems Look Like

AP dynamics (force) problems almost always involve free-body diagrams of a stationary object with multiple forces on it. Here are a couple of examples:



Q: A ball of mass *m* is suspended from two strings of unequal length as shown above. The magnitudes of the tensions T_1 and T_2 in the strings must satisfy which of the following relations?

(A) $T_1 = T_2$ (B) $T_1 > T_2$ (C) $T_1 < T_2$ (D) $T_1 + T_2 = mg$

A: Remember that forces are vectors, which have direction as well as magnitude. T_1 and T_2 each must have a vertical and horizontal component. The ball is not moving, which means there is no acceleration and therefore $F_{net} = 0$. For F_{net} to be zero, the vertical and horizontal components of all forces must cancel. This means, the vertical components of T_1 and T_2 must add up to mg, and the horizontal components of T_1 and T_2 must cancel. Therefore, answer choice (D) $T_1 + T_2 = mg$ is correct.

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Homework Problems

For each picture, draw a free-body diagram that shows all of the forces acting upon the object in the picture.

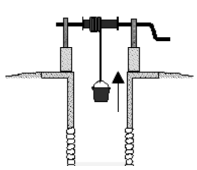
1. A bird sits motionless on a perch.

2. A hockey player glides at constant velocity across frictionless ice. (Ignore air resistance.)

3. A baseball player slides head-first into second base.

4. A chandelier hangs from the ceiling, suspended by a chain.

5. A bucket of water is raised out of a well at constant velocity.



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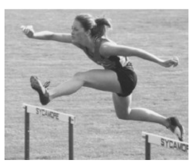
6. A skydiver has just jumped out of an airplane and is accelerating toward the ground.

7. A skydiver falls through the air at terminal velocity.

8. A hurdler is moving horizontally as she clears a hurdle. (Ignore air resistance.)



9. An airplane moves through the air in level flight at constant velocity.

10. A sled is pulled through the snow at constant velocity. (Note that the rope is at an angle.)

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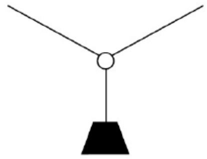
11. A stationary metal ring is held by three ropes, one of which has a mass hanging from it. (Draw the force diagram for the metal ring.)



12. A child swings on a swing. (Ignore all sources of friction, including air resistance.)

13. A squirrel sits motionless on a sloped roof.

14. A skier moves down a slope at constant velocity.

15. A skier accelerates down a slope.

Use this space for summary and/or additional notes.