

Recognizing and Interpreting Free-Body Diagrams

Purpose and Expected Outcome

In this activity, you will learn what a *free-body diagram* is. You will learn the properties of a correct free-body diagram, and you will learn how to distinguish between correct and incorrect free-body diagrams.

Prior Experience / Knowledge Needed

You should be familiar with vectors. You should know that force is a vector quantity. You should be able to identify the forces acting on a particular object. You should know the common forces used to describe and analyze large-scale objects.

FREE-BODY DIAGRAMS

As a first step in learning about free-body diagrams, you must distinguish them from a host of other drawings employed in many books in which forces (sometimes on more than one body), positions, and velocities are all indicated on a single drawing. In contrast, a free-body diagram shows all the forces acting on a single, isolated body. Only forces should be entered on a free-body diagram. The idea behind a free-body diagram is that, as Newton's laws describe, the motion of an object is completely determined by the forces exerted on the object. In essence, we replace each agent interacting with the object by the force it exerts on the object. This is why the body must be isolated (a "free" body). Indicating all of the forces acting on a single body makes it possible to discuss and determine the behavior of that body without referring to any of the objects exerting the forces.

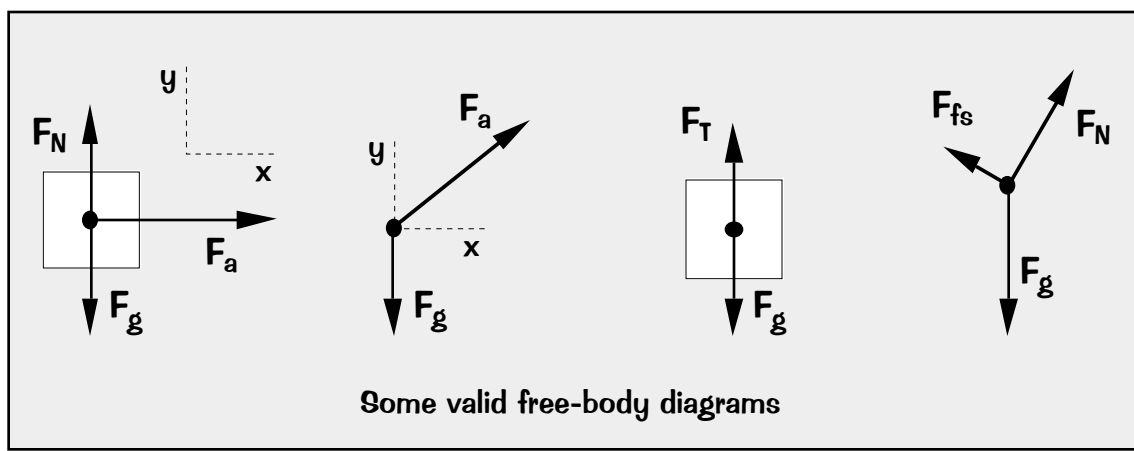


When drawing a free-body diagram it is customary to draw a point to represent the body. This point should be drawn away from any other illustration or diagram. In a free-body diagram the object is drawn as a point because Newton's laws are valid only for point objects. On this drawing, show each force exerted on the body as a directed line segment with the tail end of the vector starting at the point. The direction of the arrow should be in the same direction as the force. Whenever possible the length of the vector should be drawn to be roughly proportional to the size of the force. Each force in the diagram should be clearly labeled and distinguishable from all the other forces present in the physical situation.

When the diagram is to be used to help write the dynamical law, $\mathbf{F}_{\text{net}} = m\mathbf{a}$ in component form, a set of axes, indicating the component directions, should be drawn on the free-body diagram. These axes can be placed anywhere on the diagram but are often placed with the origin located at the point representing the center of the object. Also, these axes can be oriented in any way. Usually, the orientation is chosen to make it easier or more convenient to find components of the forces.

Sometimes, for illustration purposes, the object is drawn as having spatial extent, such as a block or square, with all the forces drawn from a point at the center of the body. When drawing the object it is important to preserve the object's orientation.

Some valid free-body diagrams are shown below. Note that: (1) only forces appear in the diagrams (and the net force should never appear); (2) a coordinate system may be shown; and (3) whether or not the body is represented for illustration, all forces begin at a point.



Explanation of Activity and Examples

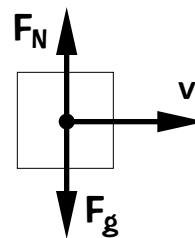
There are two parts to this activity. In the first part, you will see if you can distinguish between valid and invalid free-body diagrams that are given to you. Then in the second part you will label given free-body diagrams with the appropriate symbols to represent the forces acting on particular objects.

PART A: Recognizing Valid Free-Body Diagrams

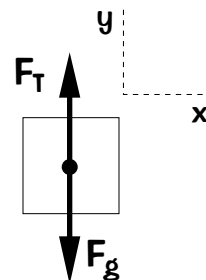
Presented below are descriptions of physical situations together with a diagram. For each case, (a) state whether or not the diagram is a valid free-body diagram. (b) If the diagram is not a valid free-body diagram, identify what makes the diagram invalid and give your reasons. **Note:** In all cases, ignore the effects of air resistance and buoyancy.

E1. A block slides along a frictionless horizontal surface with a constant velocity in the positive x -direction.

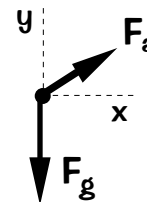
Answer: No, this diagram is not a valid free-body diagram, because the velocity is indicated. Only forces should appear on a free-body diagram.



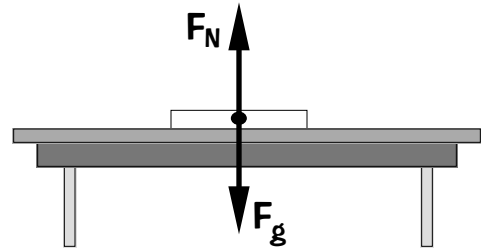
A1. A block is suspended from a massless rope.



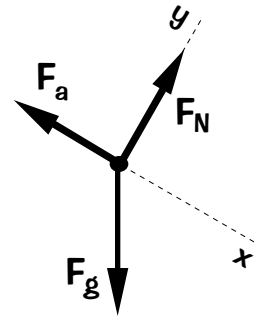
A2. A sled is pulled along a smooth (frictionless) horizontal patch of ice by an applied force directed at 30° above the horizontal.



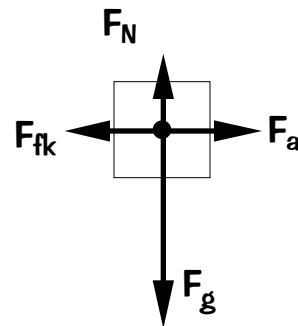
A3. A book rests on a table.



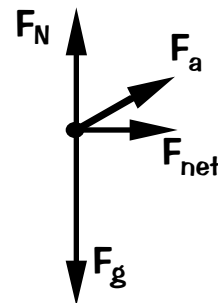
A4. An applied force F_a pushes a box up a smooth incline. The applied force is exerted parallel to the incline.



A5. A block is pulled with constant velocity along a horizontal surface having coefficient of kinetic friction μ_k .



A6. A wagon is pulled along the floor at an angle of 30° above the horizontal. Ignore frictional effects.

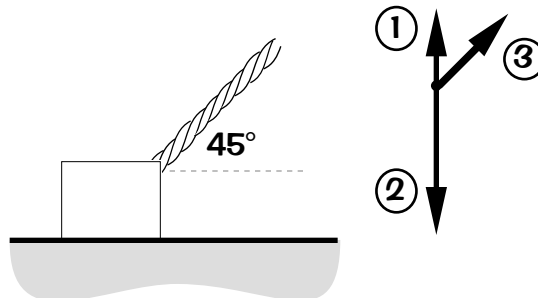


PART B: Interpreting Free-Body Diagrams

Free-body diagrams contain a lot of information. Much (but not all) of the information is contained in the presence, relative size, and orientation of each of the forces shown on the diagram.

A number of physical situations are described below, together with an illustration of each situation and a valid, but unlabeled, free-body diagram for each object in the situation. For each force in each free-body diagram, identify its source and nature. Ignore air resistance and buoyancy.

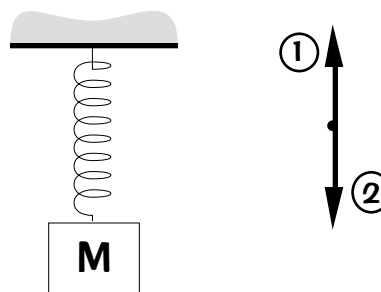
E2. A block is pulled along a frictionless, horizontal surface by a rope attached to the block. The rope is held at an angle of 45° above the horizontal as shown.



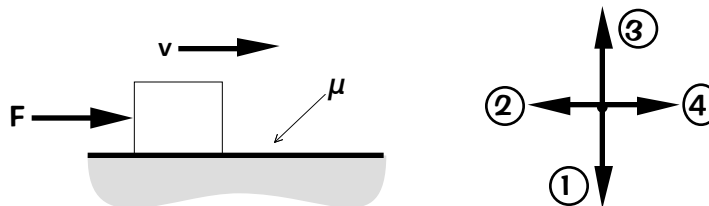
Answer:

- ① This is the Normal force exerted on the block by the horizontal surface.
- ② This is the Gravitational force exerted on the block by the earth.
- ③ This is the Tension force exerted on the block by the rope.

B1. A mass M hangs at rest from a vertical spring.

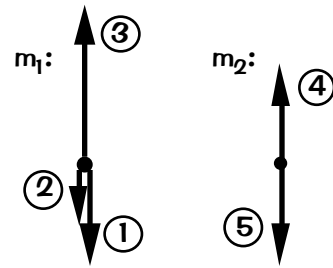
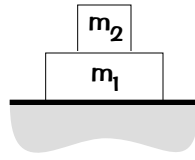


B2. A 10kg block is pushed as shown at a constant speed v along a rough, horizontal surface.

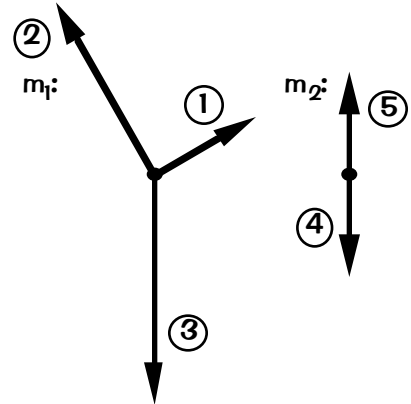
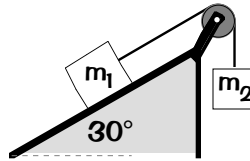


continued

- B3.** A block having mass m_1 sits at rest on a horizontal surface. A second block m_2 sits on top of the first block.



- B4.** A crate having mass m_1 sits on a frictionless incline that makes an angle of 30° with the horizontal. A rope attached to m_1 passes over a pulley at the top of the incline and has a second mass m_2 attached to its other end.



Reflection

- R1.** Fill in each blank space below with the appropriate word or phrase:

There are five features common to all free-body diagrams.

- _____ are the only vector quantities that appear in free-body diagrams; velocities, accelerations, etc. are never included. In particular, _____ force should never appear in a free-body diagram.
- _____ forces exerted on a particular object are present in the free-body diagram for the object.
- Each force is clearly _____ .
- _____ _____ object is considered in a free-body diagram.
- All forces start at a single _____ .

There are also two optional features of free-body diagrams.

- A _____ _____ may be indicated on the free-body diagram. The orientation is chosen to make finding components easier or more convenient. The placement may be either directly on the center of the diagram or off to the side.
- A _____ of the object on which the forces are exerted may be drawn on the free-body diagram, provided its orientation in the drawing is the same as its physical orientation. However, the other objects it is _____ with should never be drawn on the free-body diagram.

- R2.** How would you represent the forces present in a physical situation when there are two or more objects to consider?