

## Forces

## Key ideas

- A force is a vector quantity representing a push or a pull on one object caused by another object.
- A system is an object or collection of objects we choose to analyze. Everything outside the system is called the environment. An external force is one acting on the system due to an object in the environment.
- The **net force** is the vector sum of all forces on the system. Only external forces contribute to the net force.
- We can analyze the average motion of a system by treating it like a particle.
- A free-body diagram represents all the forces acting on a system, modeled as a particle.
- The SI unit of force is the newton (N).

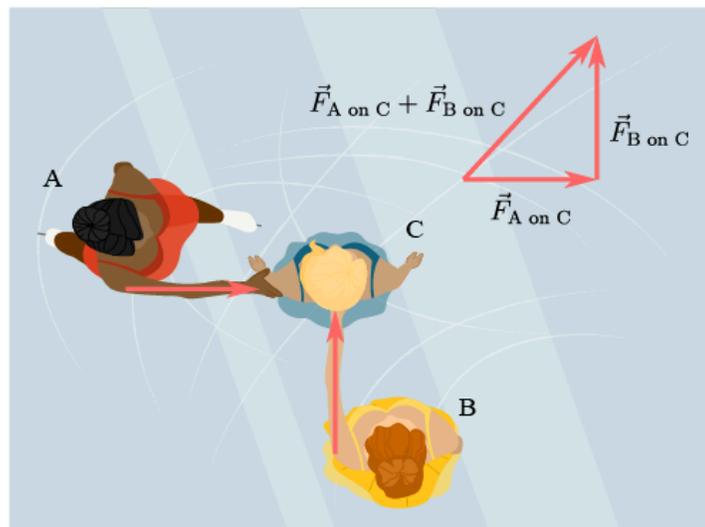
## Learning objectives

After completing this section, you should be able to...

- distinguish between a system and its environment,
- draw a free-body diagram of the forces acting on a system, and
- calculate the net force on a system, given the individual forces acting on it.

## Working Definition of Force

What exactly is a force, and how do we deal with forces quantitatively? Often in physics we might not be able to fully define a concept initially, but we can start with a "working definition" which is based on our intuition or experience. We can then make this definition more precise as we develop our understanding. Our working definition is that a **force** is a push or a pull. We know from experience that a push or a pull has both a magnitude and direction. Therefore, forces are vector quantities, and two or more forces add together as vectors. For example, consider two people pushing on a third person, as illustrated in [Figure 5.2](#). The combined effect of these two forces is the same as a single force equal to the vector sum of the original two forces.



**Figure 5.2** Two ice skaters, labeled A and B, push a third skater, labeled C, as seen from overhead. Forces are vectors and add like other vectors, so the sum of the two forces is in the direction shown.

Forces quantify **interactions** between two objects. A force on one object is always caused by another object. We will often use the notation  $\vec{F}_{A \text{ on } B}$  to indicate the force that object A exerts on object B. For example, [Figure 5.3](#) shows a man pushing a box on a sheet of ice. (We assume the ice is slippery enough to neglect friction. We also assume the man is wearing cleated shoes that "grip" into the ice.) The man exerts a force  $\vec{F}_{\text{man on box}}$  to the right. The Earth, through a "long-range" force called gravitation, exerts a force  $\vec{F}_{\text{Earth on box}}$  downward. The ice that the box lies upon exerts a force  $\vec{F}_{\text{ice on box}}$  upward.



**Figure 5.3** A man pushes a box on a sheet of ice.

## Systems and the Particle Model

We are often interested in analyzing the forces on a single object or collection of objects, which we call the **system**. Think of drawing an imaginary boundary line around whatever you are interested in analyzing. Whatever is inside the boundary is the system, and whatever is outside is called the **environment**. Any forces acting on a system must be caused by an object in the environment. The vector sum of all forces on a system is often called the **net force** on the system. In [Figure 5.3](#), the box is our system of interest.

Note that our system may include many different objects, or extended objects composed of many parts. Each object within the system may exert forces on the other constituent objects; such forces are called **internal forces**, while forces due to objects in the environment are called **external forces**. For reasons that will become clear when we study Newton's third law, only the external forces contribute to the net force on the system.

## Net Force

The net force,  $\vec{F}_{\text{net}}$ , acting on a system is the vector sum of all external forces on the system, due to objects in the environment. Mathematically,

$$\vec{F}_{\text{net}} = \sum \vec{F}$$

5.1

The motion of extended objects or systems, like people, boxes, cars or planes, can be quite complicated. Objects can rotate, vibrate, stretch, or compress. However, often we are just interested in the overall, average motion of an object or system. In such cases, we can model the system as a **particle**. In the **particle model**, the system can be imagined as a point-like object, with no structure; it does not vibrate or rotate, it simply moves along a path. You can think of this imaginary particle as an average position of the entire system. (We will further develop this idea when we discuss the concept of "center of mass" in a later chapter.)

In cases where we wish to analyze the full, complicated motion of a system, we need to pay attention to both the external forces on the system and where on the system each point is applied. However, if all we care about is the average motion of the system, we can use the particle model and treat each force as if it were acting on the particle. A diagram that depicts all the external forces acting on the particle is called a **free-body diagram**. Drawing a free-body diagram is a crucial first step in solving dynamics problems.

## PROBLEM-SOLVING STRATEGY

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### Constructing Free-Body Diagrams

Observe the following rules when constructing a free-body diagram:

1. Draw the system or object under consideration; it does not have to be artistic. At first, you may want to draw a circle around the system of interest to be sure you focus on labeling the forces acting on the system.
2. Draw all forces that act on the system, representing these forces as vectors. Remember that forces on a system are caused by objects in the environment, so consider all objects that are in contact with the system or that are exerting long-range forces on the system. Do not include the net force on the object. Do not include forces that the system exerts on objects in the environment. The picture of the system with forces directly drawn on it is sometimes called an "extended body diagram."
3. To focus more clearly on the forces, draw a separate diagram that represents the system as a dot (this dot models the system as a particle). Redraw all forces acting on the system with the vector tails at the dot. This is called the "free-body diagram."
4. It is often useful to draw an  $xy$ -coordinate system along with the free-body diagram. The particle is often at the origin of the coordinate system. You are free to choose the axes to be in any direction you like. Often it is useful to choose axes that make the calculations easier.
5. If necessary, convert the free-body diagram into a more detailed diagram showing the  $x$ - and  $y$ -components of the forces. Be careful not to "double count" a force and its components. To avoid this double counting, you may want to draw the components in a different color, erase the original forces and replace them with their  $x$ - and  $y$ -components, or even draw a second free-body diagram consisting of only the components.
6. If there are two systems in the problem, draw a separate free-body diagram for each system.

*Note:* If there is acceleration, we do not directly include it in the free-body diagram; however, it may help to indicate acceleration outside the free-body diagram.

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