5.6 Newton's Third Law

If you press against a corner of this textbook with your fingertip, the book pushes back and makes a small dent in your skin. If you push harder, the book does the same and the dent in your skin is a little larger. This simple activity illustrates that forces are interactions between two objects: when your finger pushes on the book, the book pushes back on your finger. This important principle is known as **Newton's third law**:

If two objects interact, the force $\vec{\mathbf{F}}_{12}$ exerted ON object 1 by object 2 is equal in magnitude and opposite in direction to the force $\vec{\mathbf{F}}_{21}$ exerted ON object 2 by object 1.

$$\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21} \tag{5.7}$$

When it is important to designate forces as interactions between two objects, we will use this subscript notation, where $\vec{\mathbf{F}}_{ab}$ means "the force exterted ON a by b." The third law is illustrated in Figure 5.5. The forces $\vec{\mathbf{F}}_{12}$ and $\vec{\mathbf{F}}_{21}$ in that figure are known as "third law partners".

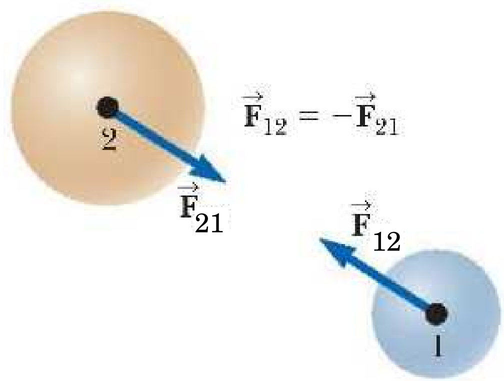

Figure 5.5 Newton's third law. The force $\vec{\mathbf{F}}_{12}$ exerted ON object 1 by object 2 is equal in magnitude and opposite in direction to the force $\vec{\mathbf{F}}_{21}$ exerted ON object 2 by object 1.

As another example, the force acting on a freely falling projectile is the gravitational force exerted ON the projectile by the Earth $\vec{\mathbf{F}}_{pE}$. The third-law partner to this force is the gravitational force exerted ON the Earth by the projectile $\vec{\mathbf{F}}_{Ep}$; this partner force accelerates the Earth toward the projectile just as the force $\vec{\mathbf{F}}_{pE}$ accelerates the projectile towards the Earth. Because the Earth has such a large mass, however, the acceleration it would have, if this partner force were the only force acting on the Earth, would be negligibly small.

Consider a computer monitor at rest on a table as in Figure 5.6a. the gravitational force ON the monitor by the Earth $\vec{\mathbf{F}}_{mE}$ has the third-law partner force $\vec{\mathbf{F}}_{Em}$ which is the gravitational force ON the Earth by the monitor (this force is effectively acting at the center of the Earth). The monitor does not accelerate because there is a second force on the monitor, the electromagnetic contact force ON the monitor by the table $\vec{\mathbf{F}}_{mt}$; this upward force is often called a **normal force** ("normal" is a synonym for "perpendicular") because it is perpendicular to the surfaces of contact. For this reason, the force $\vec{\mathbf{F}}_{mt}$ is often denoted as $\vec{\mathbf{n}}_{mt}$. This force, which prevents the monitor from falling through the table, can have any value needed, up to the point of breaking the table. Because the monitor is observed to have zero acceleration, Newton's second law applied to the monitor gives $\Sigma\vec{\mathbf{F}} = \vec{\mathbf{n}}_{mt} + m\vec{\mathbf{g}} = 0$, so that in magnitudes $n_{mt} = mg$. The normal force ON the monitor by the table balances the gravitational force ON the monitor by the Earth, so the net force ON the monitor is zero. The third-law partner force to $\vec{\mathbf{n}}_{mt}$ is the normal force exerted downward ON the table by the monitor $\vec{\mathbf{n}}_{tm}$; i.e. $\vec{\mathbf{n}}_{mt} = -\vec{\mathbf{n}}_{tm}$.

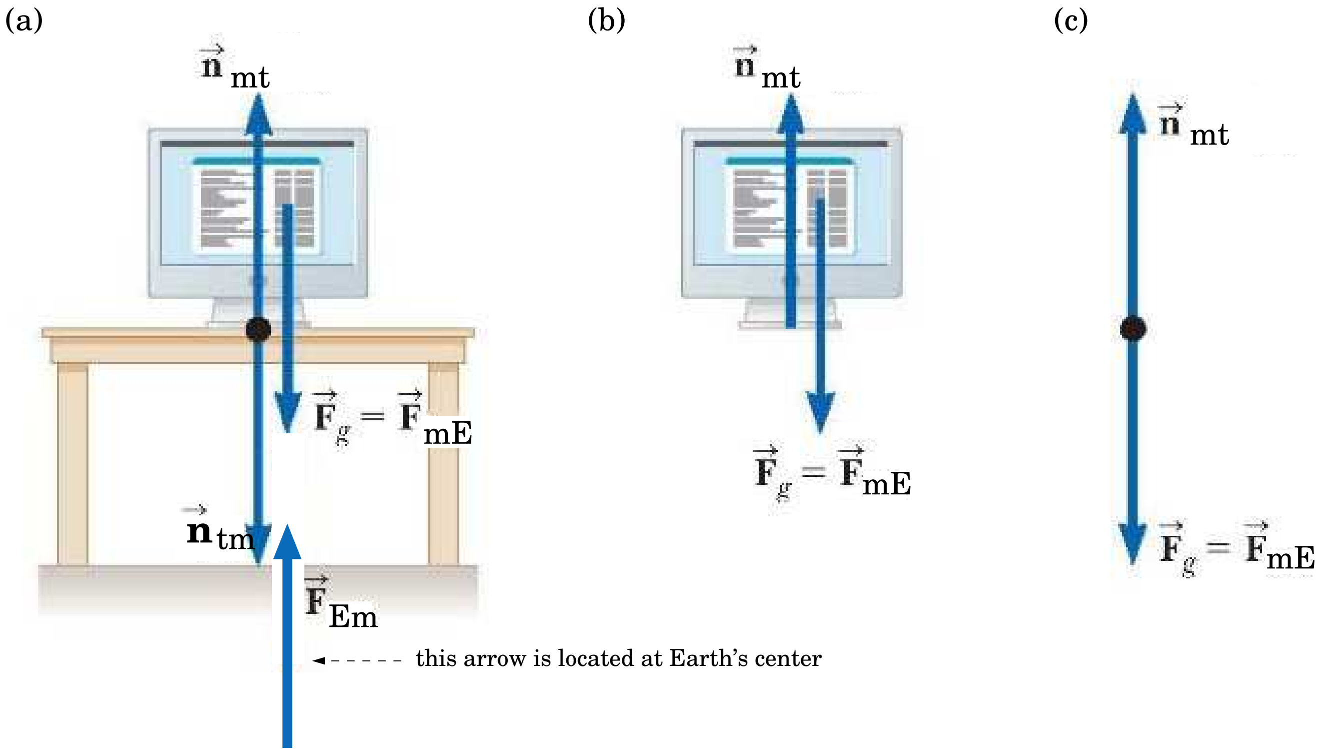

Figure 5.6 (a) When a computer monitor is at rest on a table, the forces acting on the monitor are the normal force $\vec{\mathbf{n}}_{mt}$ and the gravitational force $\vec{\mathbf{F}}_g$. The third-law partner to $\vec{\mathbf{n}}_{mt}$ is the normal force exerted ON the table by the monitor $\vec{\mathbf{n}}_{tm}$. The third-law partner to $\vec{\mathbf{F}}_g$ is the force $\vec{\mathbf{F}}_{Em}$ exerted ON the Earth by the monitor. (b) A diagram showing all the forces acting ON the monitor. (c) A free-body diagram shows the monitor as a black dot with the forces acting on it.

Notice that the forces acting ON the monitor are $\vec{\mathbf{F}}_{mE}$ and $\vec{\mathbf{n}}_{mt}$ as shown in Figure 5.6b. The two forces $\vec{\mathbf{F}}_{Em}$ and $\vec{\mathbf{n}}_{tm}$ are exerted on the Earth and the table respectively.

Pitfall Prevention 5.6

n **Does Not Always Equal** mg

In the situation shown in Figure 5.6, we find that $n_{mt} = mg$ (the normal force on the monitor has the same magnitude as the gravitational force on the monitor). This result is *not* generally true. If an object is on an incline, if there are applied forces with vertical components, or if there is a vertical acceleration of the system, the normal force on an object does not have the same magnitude as the gravitational force on that same object. *Always* apply Newton's second law to find the relationship between n and mg.

Pitfall Prevention 5.7

Newton's Third Law

Remember that Newton's third-law partner forces act on *different* objects. For example, in Figure 5.6, the forces $\vec{\mathbf{n}}_{mt}$ and $\vec{\mathbf{F}}_{mE}$ are equal in magnitude and opposite in direction, but they cannot possibly be third-law partners because both forces act on the *same* object, the monitor.

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