

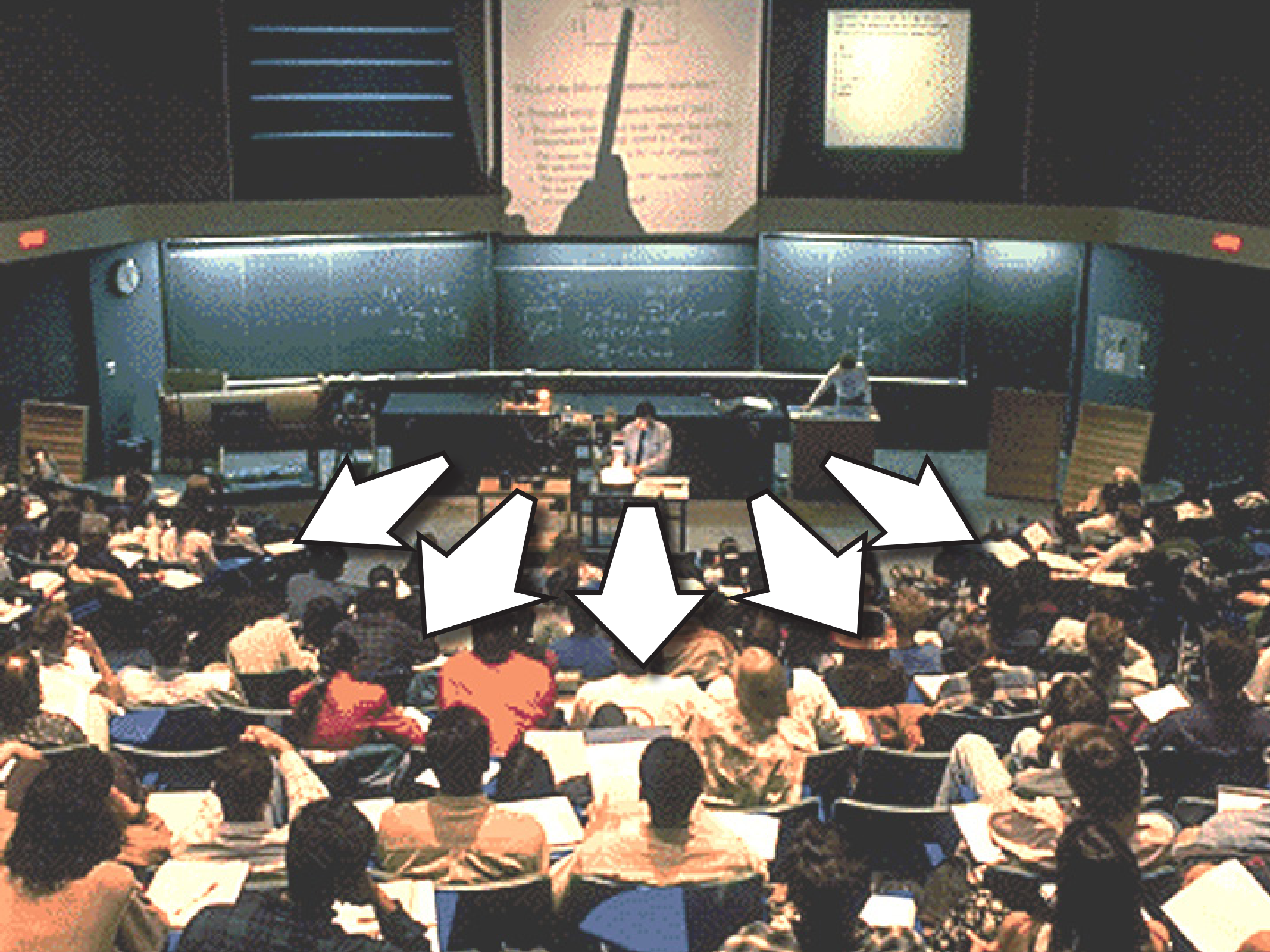
Getting every student prepared for every class



@eric_mazur

Kent State University
Kent, OH, 24 February 2017







CLASS

1st exposure



ROOM

deeper understanding



CLASS

1st exposure



ROOM

deeper understanding



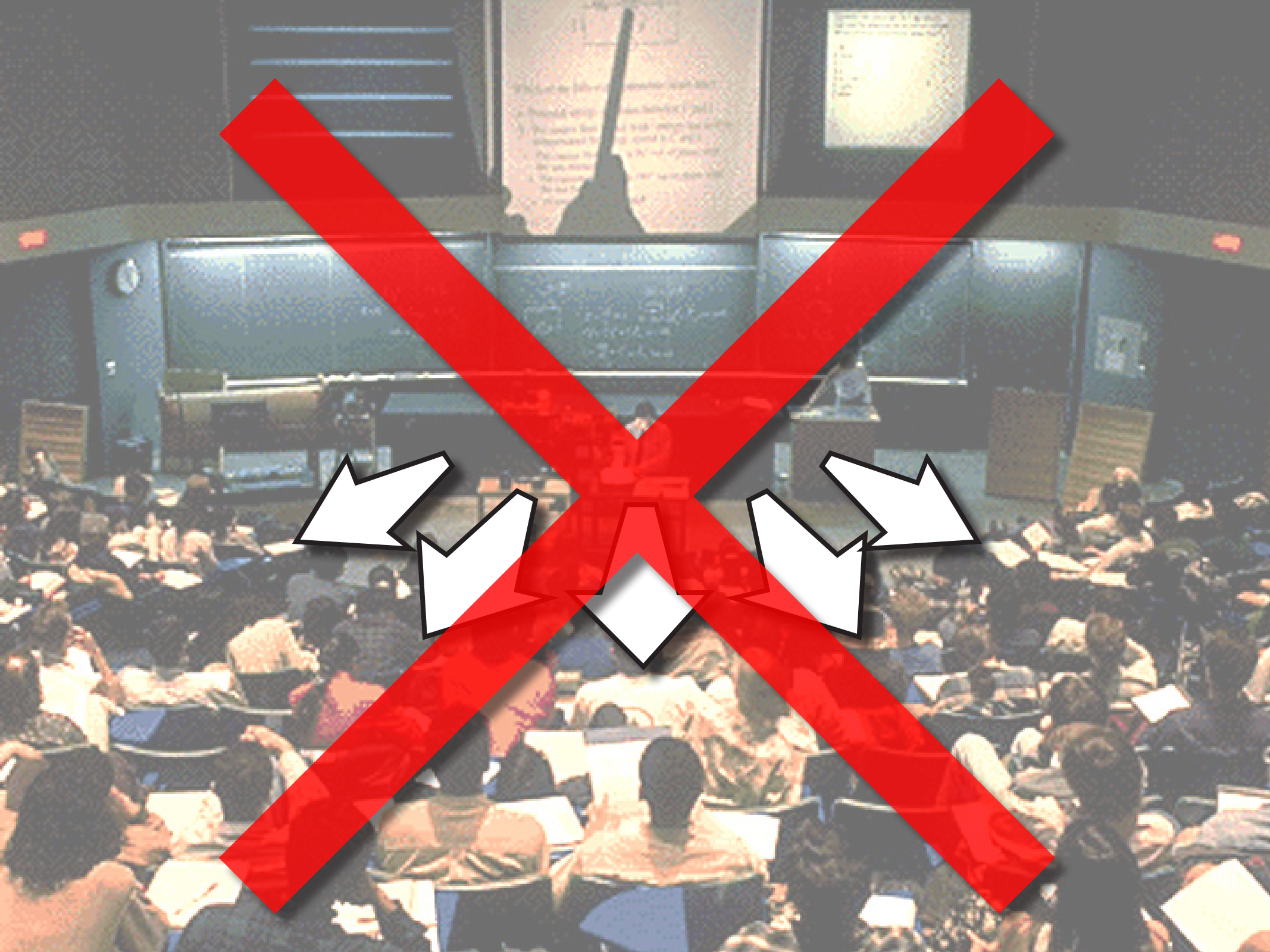
ROOM

1st exposure

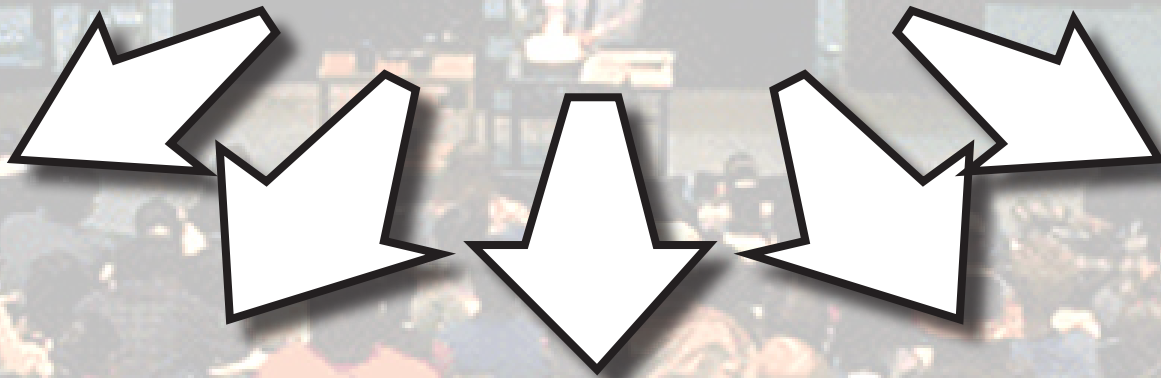


CLASS

deeper understanding



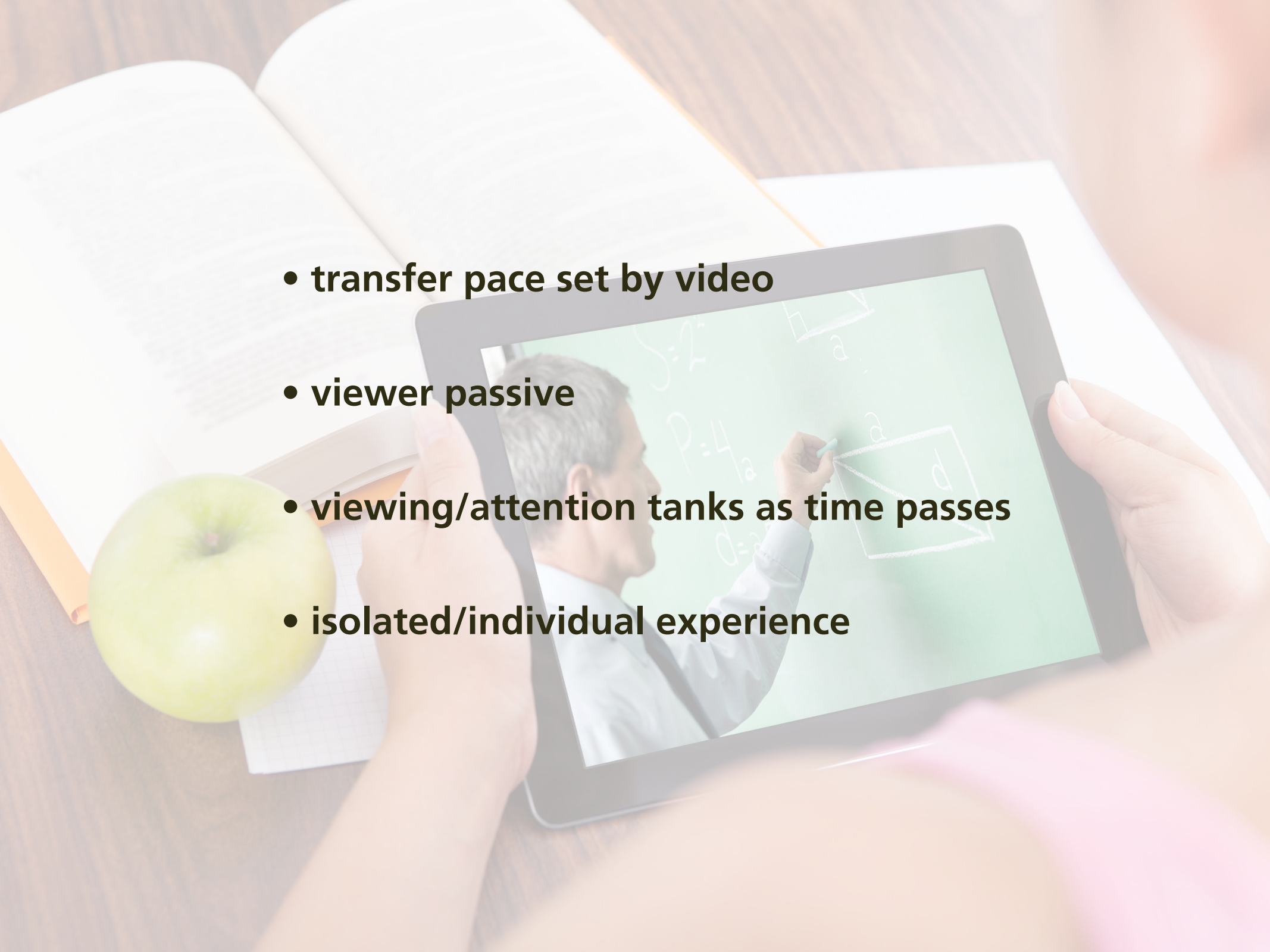
how to effectively transfer information outside classroom?





but...

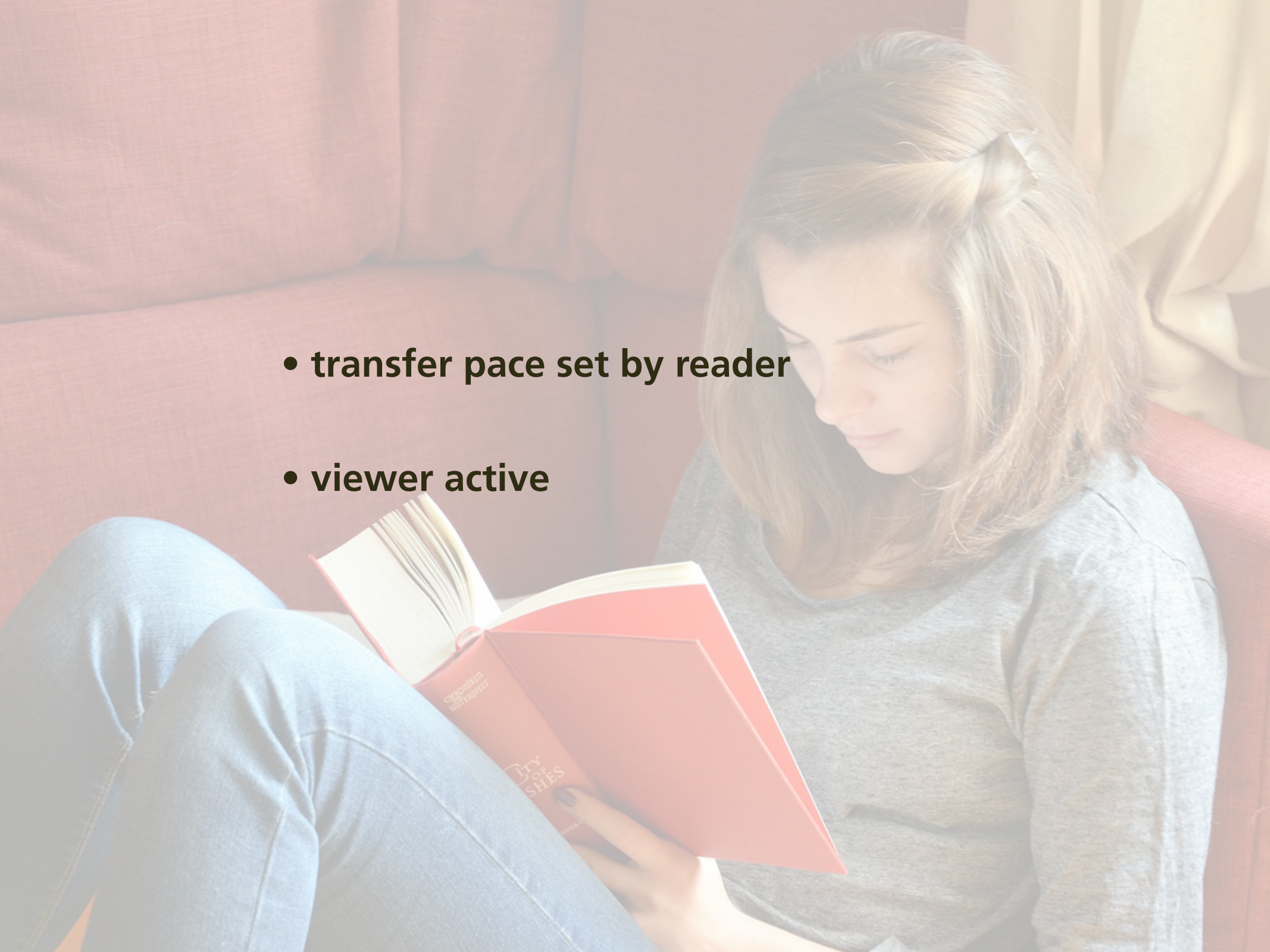


- 
- transfer pace set by video
 - viewer passive
 - viewing/attention tanks as time passes
 - isolated/individual experience



we're simply moving this outside classroom!



- 
- **transfer pace set by reader**
 - **viewer active**

but...





**isolated/individual experience &
no real accountability**



want:
every student prepared for every class



want:
***every* student prepared for *every* class**
(without additional instructor effort)

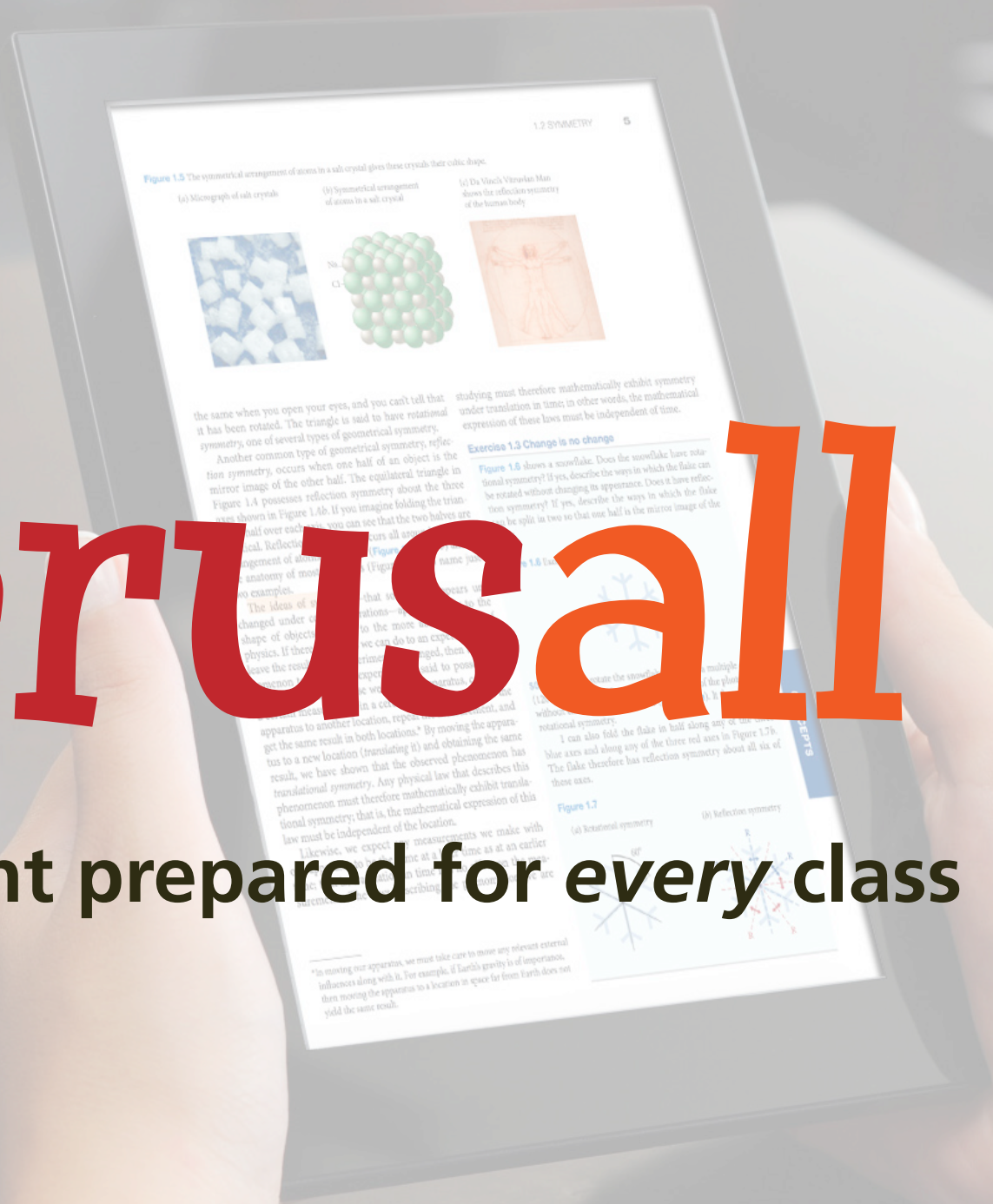
A stylized illustration of a classroom. Several students are seated at rows of desks, facing forward. The students are depicted in various colors (yellow, green, blue, purple, pink, light green) and are holding pens or pencils, suggesting they are in a lecture or study session. The background is a solid light gray.

Solution

**turn out-of-class component
also into a social interaction!**

Perusall

every student prepared for every class



76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough. Notice that you have had this everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice; it is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction surface—like a smooth surface of water. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This is not a new or everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval of motion, the velocity decreases over time. The velocity decreases over time on ice is hardly observable. The velocity decreases over time on a rough surface because there is very little friction. The velocity decreases over time on a rough surface because there is very little friction. The effect of friction is to slow down the motion of the block with respect to each other—in this case, the block and the surface it is sliding on. The longer it takes for the block to come to rest, the less friction there is.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with an air track, in which a track has many small holes with air coming out of them, which reduces friction. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the carts shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For the carts shown in Figure 4.2 is horizontal, carts move without slowing down appreciably. In the absence of friction, the carts would move along a horizontal track without slowing down.

In the absence of friction, the carts would move along a horizontal track without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this may happen very quickly. If the surfaces are slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice; it hardly decreases on the rough surface. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the force that opposes the motion of an object encountered during the interaction. In the velocity-versus-time graph, the velocity decreases as the block slides over ice is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows the track and carts used in the experiments described in this chapter. In your book, both for Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The rougher the surface, the more quickly the velocity decreases due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. The track shown in Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

...opens chat window



Enter your comment or question and press Enter

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice; it is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

Enter your comment or question and press Enter

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice; it is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

No friction at all seems impossible. Isn't there always some friction in any real case?

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice; this is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

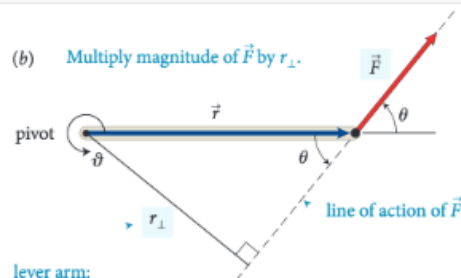
? No friction at all seems impossible. Isn't there always some friction in any real case.

Nov 1 4:41 pm



Enter your comment or question and press Enter



(b) Multiply magnitude of \vec{F} by r_{\perp} .

lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be written equivalently as rF_{\perp} and as $r_{\perp}F$.

Like other rotational quantities, torque carries a sign that depends on the choice of direction for increasing ϑ . In Figure 12.4, for example, the torque caused by \vec{F}_1 about the pivot tends to rotate the rod in the direction of increasing ϑ and so is positive; the torque caused by \vec{F}_2 is negative. The sum of the two torques about the pivot is then $r_1F_1 + (-r_2F_2)$. As we've seen, the two torques are equal in magnitude when the rod is balanced, and so the sum of the torques is zero. When the sum of the torques is not zero, the rod's rotational acceleration is nonzero, and so its rotational velocity and angular momentum change.

In the situations depicted in Figures 12.4 and 12.5 we used the pivot to calculate the lever arm distances. This is a natural choice because that is the point about which the object under consideration is free to rotate. However, torques also play a role for stationary objects that are suspended or supported at several different points and that are not free to rotate—for example, a plank or bridge supported at either end. To determine what reference point to use in such cases, complete the following exercise.

Exercise 12.1 Reference point

Consider again the rod in Figure 12.4. Calculate the sum of the torques about the left end of the rod.

SOLUTION I begin by making a sketch of the rod and the three forces exerted on it, showing their points of application on the rod (Figure 12.6).

reference point



The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

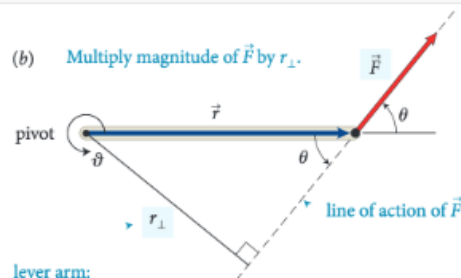
For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_3 are equal in magnitude, and the magnitude of \vec{F}_2 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

(b) Multiply magnitude of \vec{F} by r_{\perp} .

lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

reference point

 \vec{F}_1

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever


Three forces are exerted on the lever of **Figure 12.7**. Forces \vec{F}_1 and \vec{F}_3 are equal in magnitude, and the magnitude of \vec{F}_2 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?


? I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque. Oct 20 12:09 am


? I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

? This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

Enter your comment or question and press Enter

 I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

 SB I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

 This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

Enter your comment or question and press Enter




don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some other direction to calculate torque.





I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.



This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

 I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

 I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

 This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

Enter your comment or question and press Enter


I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.


This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

"helps me" flag



 I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

Oct 20 12:09 am

 I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

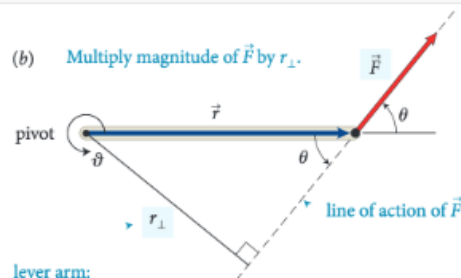
Oct 20 12:38 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Oct 22 8:48 pm

+1 

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_3 are equal in magnitude, and the magnitude of \vec{F}_2 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

? I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

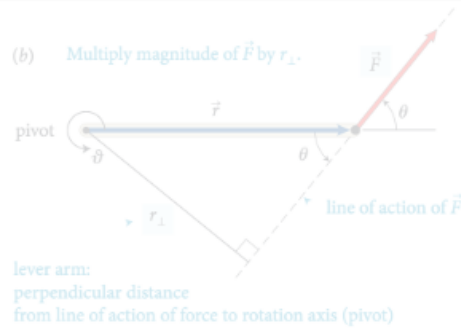
? I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

? This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

Enter your comment or question and press Enter

quickly navigate all comments

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must be determined about the left end of the rod. The lever arm distance of \vec{F}_1 about the left end of the rod is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

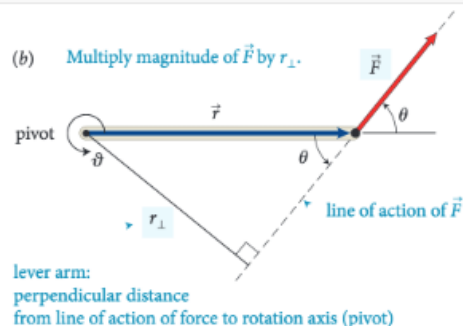
Three forces are exerted on the lever of **Figure 12.7**. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

? I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

? I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

? This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

Enter your comment or question and press Enter

(b) Multiply magnitude of \vec{F} by r_{\perp} .

lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

reference point

 \vec{F}_1

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_3 are equal in magnitude, and the magnitude of \vec{F}_2 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

Oct 20 12:09 am

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

Oct 20 12:38 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Oct 22 8:48 pm

Enter your comment or question and press Enter

email notifications

Brian Lukoff responded to a question in Mazur Chapter 4 Sample that you wanted to know the answer to

21 minutes ago, you asked this question on Perusall:

No friction at all seems impossible. Isn't there always some friction in any real case?

Brian Lukoff just responded to the question by saying:

Right - I think there will always be some friction due to the second law of thermodynamics.

If this helps your understanding, click the button below. If you want to respond, simply reply to this email to post to Perusall.

[View conversation](#)

[This comment helps my understanding](#)

email notifications

Brian Lukoff responded to a question in Mazur Chapter 4 Sample that you wanted to know the answer to

21 minutes ago, you asked this question on Perusall:

No friction at all seems impossible. Isn't there always some friction in any real case?

Brian Lukoff just responded to the question by saying:

Right - I think there will always be some friction due to the second law of thermodynamics.

option 1: reply

If this helps your understanding, click the button below. If you want to respond, simply reply to this email to post to Perusall.

[View conversation](#)

[This comment helps my understanding](#)

email notifications

Brian Lukoff responded to a question in Mazur Chapter 4 Sample that you wanted to know the answer to

21 minutes ago, you asked this question on Perusall:

No friction at all seems impossible. Isn't there always some friction in any real case?

Brian Lukoff just responded to the question by saying:

Right - I think there will always be some friction due to the second law of thermodynamics.

If this helps your understanding, click the button below. If you want to respond,

option 2: view chat

View conversation

This comment helps my understanding

email notifications

Brian Lukoff responded to a question in Mazur Chapter 4 Sample that you wanted to know the answer to

21 minutes ago, you asked this question on Perusall:

No friction at all seems impossible. Isn't there always some friction in any real case?

Brian Lukoff just responded to the question by saying:

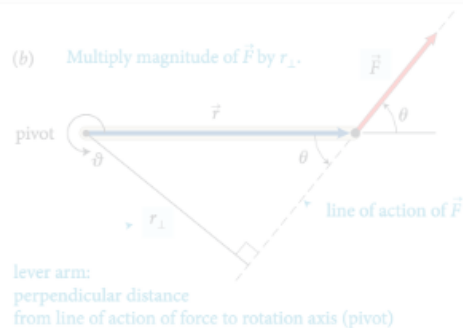
Right - I think there will always be some friction due to the second law of thermodynamics.

If this helps your understanding, click the button below. If you want to respond, simply reply to this comment.

View conversation

This comment helps my understanding

option 3: mark as answered



action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the right end of the rod and find the same result. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

how to get students to participate?

I don't understand how this combination of factors tells you the direction of the lever arm distance. I see you're talking about some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

The periods of when we ...

torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

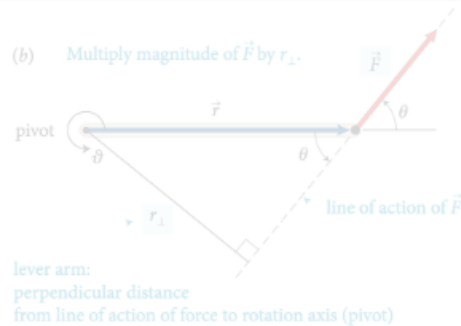
(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

(b) Multiply magnitude of \vec{F} by r_{\perp} .

lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and the lever arm distance.

use combination of

intrinsic and extrinsic motivation drivers

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

Oct 20 12:09 am

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

Oct 20 12:09 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Oct 22 8:48 pm

Enter your comment or question and press Enter

reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

For a stationary object, the sum of the torques is zero. For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

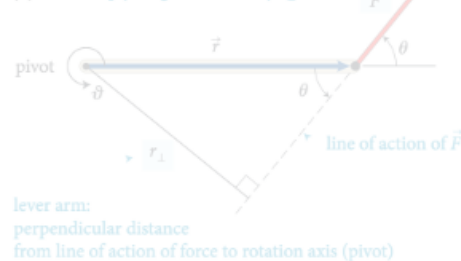
Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

rubric-based assessment

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs, the torque balance equation is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

must demonstrate thoughtful reading & interpretation

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

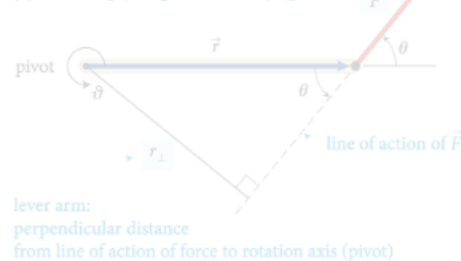
Enter your comment or question and press Enter

rubric-based assessment

must demonstrate thoughtful reading & interpretation

- quantity (10–20)

(b) Multiply magnitude of \vec{F} by r_{\perp} .



action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs, the torque sum is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

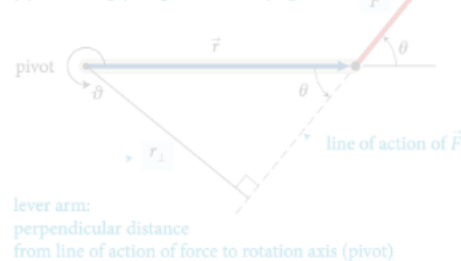
I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

rubric-based assessment

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs, the torque sum is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

must demonstrate thoughtful reading & interpretation

- quantity (10–20)

- timeliness (before class)

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So, after multiplying the distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

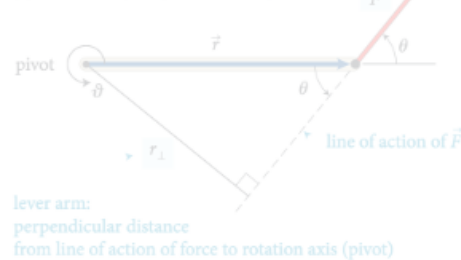
Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

rubric-based assessment

(b) Multiply magnitude of \vec{F} by r_{\perp} .



action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs, the torque sum is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point where a force is exerted, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

must demonstrate thoughtful reading & interpretation

- quantity (10–20)

- timeliness (before class)

- distribution (not clustered)

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

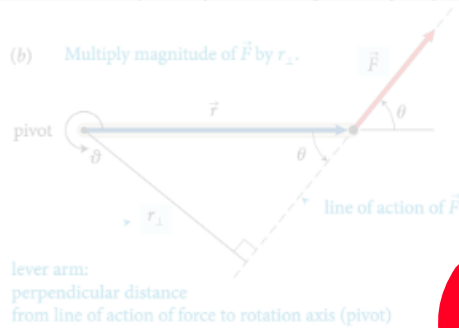
Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

rubric-based assessment

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

- quality (thoughtful reading & interpretation)

- quantity (minimum)

- timeliness (before class)

- distribution (not clustered)

over 20,000 annotations!

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 about the left end of the rod is zero, and so the torque caused by this force about the left end of the rod is zero. If I choose the counter-clockwise direction as positive for rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_3 causes a positive torque about the left end of the rod. The lever arm distance for \vec{F}_2 is the perpendicular distance from the left end of the rod to the line of action of \vec{F}_2 . This is the same as the distance from the left end of the rod to the point of application of \vec{F}_2 , since \vec{F}_2 is perpendicular to the rod. The lever arm distance for \vec{F}_3 is the perpendicular distance from the left end of the rod to the line of action of \vec{F}_3 . This is the same as the distance from the left end of the rod to the point of application of \vec{F}_3 , since \vec{F}_3 is perpendicular to the rod. The sum of the torques about the left end of the rod is $\tau = -F_2 r_2 + F_3 r_3$. The result is that the net torque is zero, and the rod is in equilibrium.

For the sum of the torques about the left end of the rod to be zero, just like the sum of the forces about the pivot, you can repeat the calculation for the torques about the right end of the rod for any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques is zero about any point. In general we can choose any point as the reference point for calculating the sum of the torques.

For a rotating object, we choose a reference point and we like to calculate the torque relative to a reference point that is convenient for the calculation. As you have seen, we do not need to know any details about the forces at the reference point, only the distance from the reference point to the point of application of the force. We can calculate that force from the acceleration of the point of application.

12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the left, we see th...

It's interesting that the white ...

Is it better to have a frame i...

How does this affect ...

As we saw earlier in this, t...

Understand the physical w...

This class says emp...

Before this wa...

The extended free-body

This just means the net

I don't understand why ...

It is important that...

ends when we ...

Equilibrium is abso...

Typical diagram to u...

Remember the i...

When we have a p...

Since torque is the cross pro...

The right-hand rule can al...

I don't understand how ...

Orientation-based descriptio...

I don't really understand...

How small is small? As ...

I think it would be slightly ...

While I believe I underst...

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod...

Does torque have the s...

rubric-based assessment

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

- quality (thoughtful reading & interpretation)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. In general, for any stationary object, the sum of the torques is zero. For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point where a force is exerted, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

how do you process all of that??

- timeliness (before class)

- distribution (not clustered)

lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So rather than trying to get the magnitude and direction, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, you can think of this in terms of the torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

is important to the th...

this means that when we...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

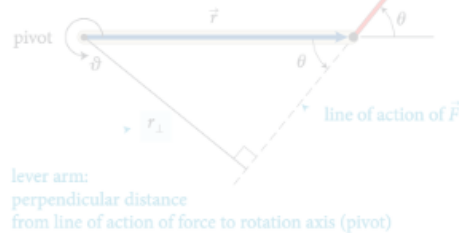
Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

rubric-based assessment

(b) Multiply magnitude of \vec{F} by r_{\perp} .



- quality (though future could be automated interpretation)

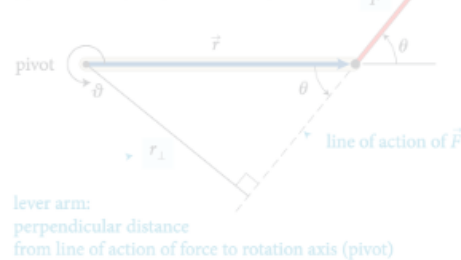
- timeliness (before class)
- distribution (not clustered)

12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of **Figure 12.7**. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

fully automated assessment

(b) Multiply magnitude of \vec{F} by r_{\perp} .

- specialized machine learning algorithm
- assesses intellectual content
- exceeds intercoder reliability

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like you would have to know some sort of direction to determine the direction of the torque.

Oct 20 12:09 am

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. The question is, how do you explain how to choose the sign?

Oct 20 12:38 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Oct 22 8:48 pm

Enter your comment or question and press Enter

reference point

 \vec{F}_1

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about any point is zero.

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and one time you will find that the sum of the torques is zero. The result is that the sum of the torques about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point. We like to choose the pivot as a reference point because it is the point about which the object is rotating. But that is not the only point we can choose. In fact, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

gradebook

Gradebook

Click on a grade to see details about the student's assignment.

Copy to clipboard

Download

Search:

Student Name	Student ID	Chapter 1	Chapter 2	Ch
[blurred]		3	2	
[blurred]		3	3	
[blurred]		3	3	
[blurred]				
[blurred]		3	3	
[blurred]		3		
[blurred]		1	2	
[blurred]				
[blurred]		0		
[blurred]		3	3	

Release to students

Release to students

Re

gradebook

Gradebook

Click on a grade to see details about the student's assignment.

Copy to clipboard

Download

Search:

Student Name	Student ID	Chapter 1	Chapter 2	Ch
[REDACTED]		3		
[REDACTED]		3		
[REDACTED]		3		
[REDACTED]				
[REDACTED]		3		
[REDACTED]		3		
[REDACTED]		3		
[REDACTED]		1		
[REDACTED]				
[REDACTED]		0		
[REDACTED]		3		

Total number of annotations **16**

Total number of annotations submitted on time **11**

Average quality of top 10 annotations submitted on time **1.80**

2 = demonstrates thorough and thoughtful reading and insightful interpretation of the reading, 1 = demonstrates reading, but no (or only superficial) interpretation of the reading, 0 = does not demonstrate any thoughtful reading or interpretation

Distribution of annotations **3.8**

0 = clustered, 5 = evenly distributed throughout assignment

Assignment score **1**

scores range from 0 to 3

LMS integration

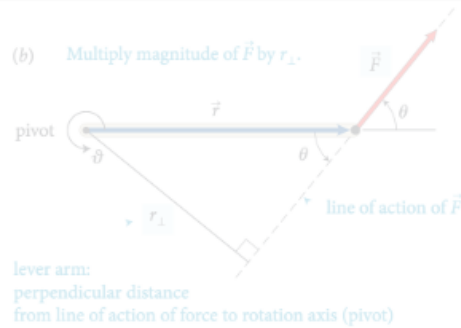
- Single sign-on from LMS to Perusall
- Gradebook sync between Perusall and LMS
- Compatible with many modern LMSs

The screenshot displays the Perusall LMS interface. At the top, the Perusall logo and navigation links are visible. The main content area shows a physics textbook page titled "AP50 Fall 2015 » Chapter 12" with a diagram of a lever arm and a force vector. The diagram is labeled (b) and shows a horizontal rod with a pivot at the left end. A force vector \vec{F} is applied at the right end, making an angle θ with the horizontal. The lever arm is labeled r_1 and the line of action of the force is labeled r_2 . The text explains that the lever arm distance must be determined relative to the left end of the rod, and that the sum of the torques about the left end of the rod is zero.

On the right side, there is a sidebar with a list of questions and answers. The questions are:

- On the very left, we see th...
- It's interesting that the white ...
- Is the reference frame i...
- How does force affect ...
- I was curious about this, t...
- I understand partially w...
- In this class, we always emp...
- The part before this wa...
- The extended free-body d...
- ... just means the net...
- I don't understand why ...
- It is important to note that...
- This reminds me of when we ...
- ... of ...
- The type of diagram to use d...
- It sounds like it is sayin...
- So then do we have a p...
- ... is the cross pro...
- The right-hand rule can al...
- I don't understand how ...
- Orientation-based descriptio...
- I don't really understand...
- How small is small? As ...
- I think it would be slightly ...
- While I believe I underst...
- (a) The change in rotationa...
- As we saw earlier in the chap...
- Objects executing motion ar...
- Generally, for rotating bod...
- Does torque have the s...

At the bottom, there is a chat area with a text input field and a "Enter" button. The chat area shows a conversation between a user and a tutor, discussing the torque equation and the lever arm distance.



action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

connect pre-class and in-class activities

I don't think you can calculate torque without knowing the direction of the force. Even if you know the magnitude of the force, you need to know the direction of the force to calculate the torque. It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

On the very left, we see th...

It's interesting that the white ...

Is the refernece frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This is a good question when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

Confusion report for Chapter 24

right hand rule (11 questions)

- JB Can someone in simpler terms explain the right- hand rule? +1
- WJ Is there another way, besides the right hand rule, to find the direction of the magnetic field with a current? 2
- SB Using the right hand rule, I believe the answer is D. Is that correct? 3
Show more...

direction magnetic field (8 questions)

- CP Why is it that the magnet field points away from the north pole and towards the south pole? When on the previous page it stated that the direction of the magnetic field is the direction that the north pole of a compass needle points. +2
- AB How can you determine which direction the magnetic field will point towards? +1
- KH So whichever way the north pole faces is the direction of the magnetic field but that doesn't always mean its pointing true north? +1
Show more...

earth magnetic field (6 questions)

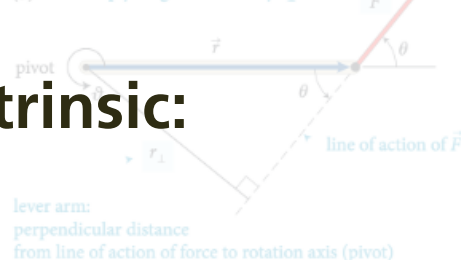
- CP Does that mean that the compass will be distracted from the Earth's magnetic field and use the magnetic field that the current of the wire gives off? 2
- AK Can someone explain why this type of bacteria knows what direction the earth's magnetic fields are facing? 3
- J Does the circular loop of current have any similarities with the look of the earths magnetic field? They kind of look similar to me. 3
Show more...

motivating factors

Intrinsic:

• social interaction

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

Oct 20 12:09 am

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

Oct 20 12:38 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Oct 22 8:48 pm

Enter your comment or question and press Enter

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

motivating factors

Intrinsic:

- social interaction
- tie-in to in-class activity

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. We can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

I don't understand how this com...
factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

motivating factors



Intrinsic:

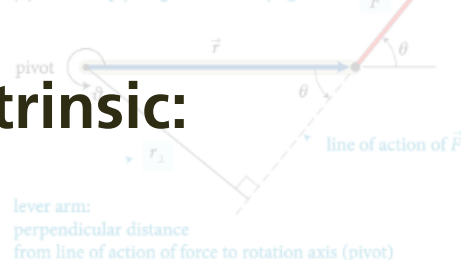
- social interaction

- tie-in to in-class activity

Extrinsic:

- assessment (fully automated)

(b) Multiply magnitude of \vec{F} by r_{\perp} .



action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. We can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point where a force is exerted, we can ignore that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

I don't understand how this comment... factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. If you know the magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

motivating factors

"I think the Perusall app and annotation system is way better than just reading a textbook normally... I've been reading for almost four hours now and haven't gotten bored"

Harvard student

The screenshot displays the Perusall app interface. At the top, the browser address bar shows 'app.perusall.com'. The app header includes the 'Perusall' logo, the course 'AP50 Fall 2015 » Chapter 12', and the user 'Eric Mazur'. The main content area shows a physics textbook page with a diagram of a lever and text explaining torque. Overlaid on the right side is a list of student annotations, each with a question mark icon, a snippet of text, and a count of other users who annotated the same spot. The annotations include questions like 'On the very left, we see th...', 'It's interesting that the white ...', 'Is the reference frame i...', 'How does force affect ...', 'I was curious about this, t...', 'I understand partially w...', 'The part before this wa...', 'The extended free-body d...', 'I don't understand why ...', 'It is important to note that...', 'Torque is the ability of a forc...', 'the type of diagram is d...', 'So then do we have a p...', 'Since torque is the cross pro...', 'The right-hand rule can al...', 'I don't really understand...', 'How small is small? As ...', 'I think it would be slightly ...', 'While I believe I underst...', '(a) The change in rotationa...', 'As we saw earlier in the chap...', 'Objects executing motion ar...', 'Generally, for rotating bod...', and 'Does torque have the s...'. The bottom of the screen shows a comment input field with the placeholder text 'Enter your comment or question and press Enter'.

motivating factors

"It makes the book fun to read..."

All the other students on my floor are disappointed their Prof isn't using Perusall because they don't read the book."

Ohio State student

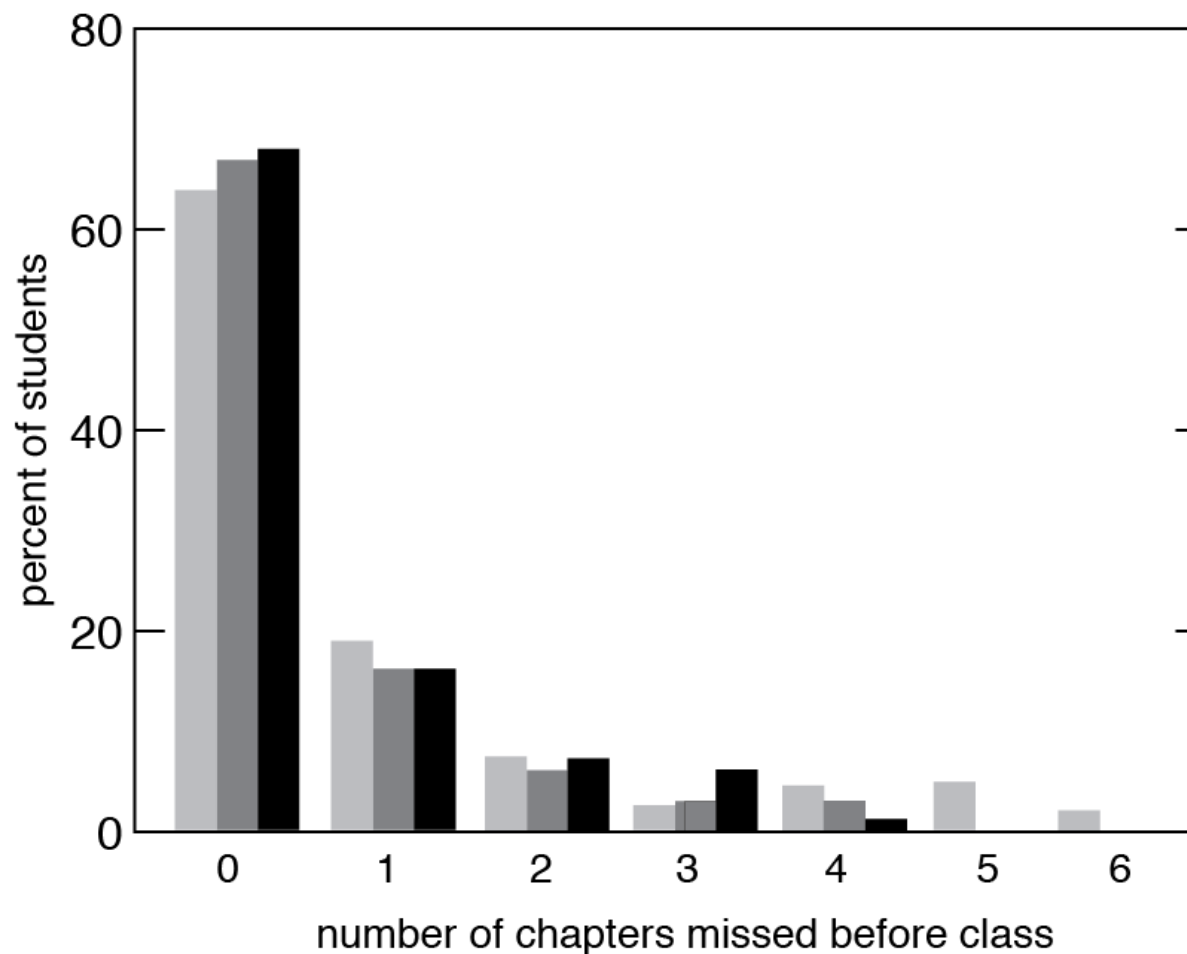
class test results

(b) Multiply magnitude of \vec{F} by r_{\perp} .

\vec{F}

Reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this



On the very left, we see th...

It's interesting that the white ...

a reference frame i... 2

does force affect ... 2

curious about this, t... 3

understand partially w... 3

class, we always emp... 2

part before this wa... 2

ended free-body d... 4

just means the net... 3

it understand why ... 3

important to note that... 2

minds me of when we ...

is the ability of a forc...

of diagram to use d...

nds like it is sayin... 3

en do we have a p... 5

orque is the cross pro...

nt-hand rule can al... 3

it understand how ... 3

tion-based descriptio...

it really understand... 2

small is small? As ... 3

it would be slightly ...

I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

class test results

(b) Multiply magnitude of \vec{F} by r_{\perp} .

\vec{F}

Reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this

Page 284

Eric Mazur

On the very left, we see th...

It's interesting that the white ...

a reference frame i... 2

does force affect ... 2

curious about this, t... 3

understand partially w... 3

class, we always emp... 2

part before this wa... 2

ended free-body d... 4

just means the net... 3

it understand why ... 3

important to note that... 2

minds me of when we ... 3

is the ability of a forc... 3

re of diagram to use d... 3

nds like it is sayin... 3

en do we have a p... 5

orque is the cross pro... 3

nt-hand rule can al... 3

it understand how ... 3

tion-based descriptio... 2

it really understand... 2

small is small? As ... 3

it would be slightly ... 3

I believe I underst... 3

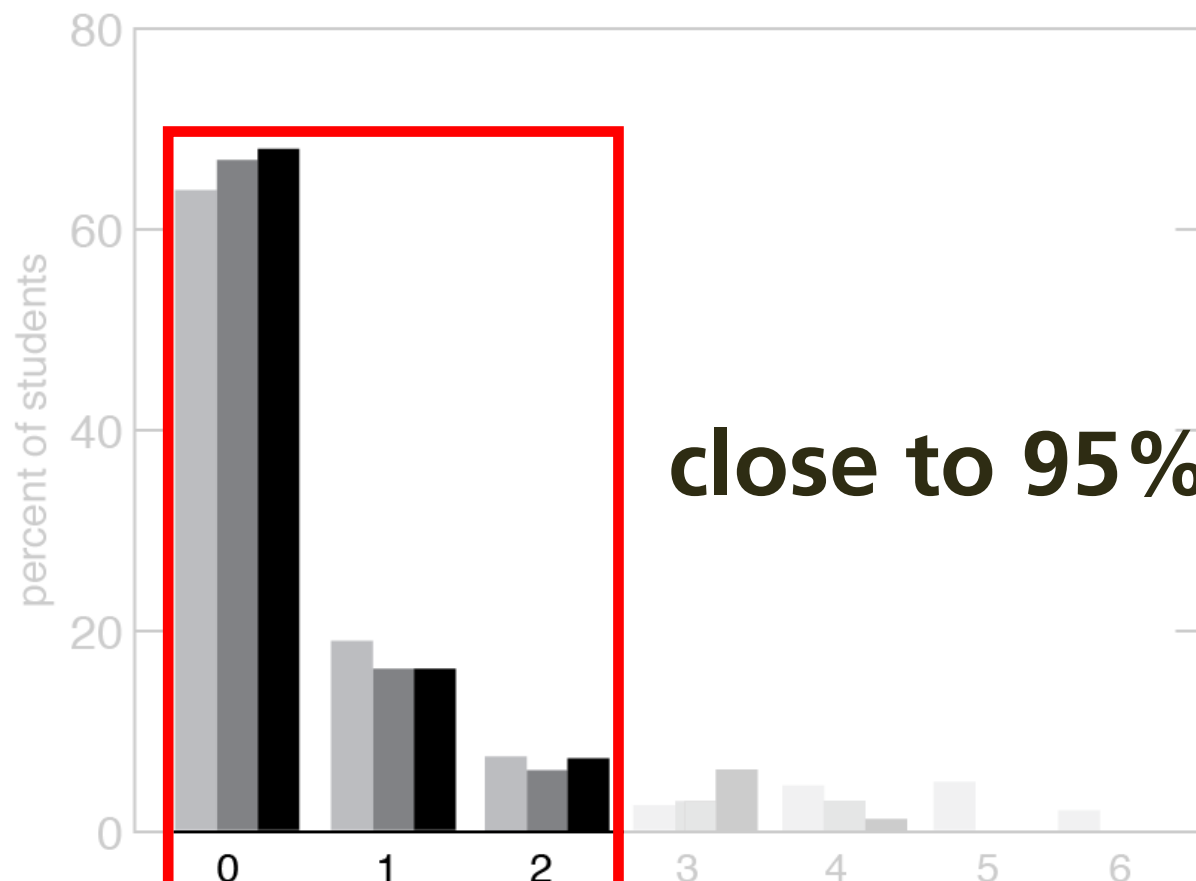
(a) The change in rotation...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3



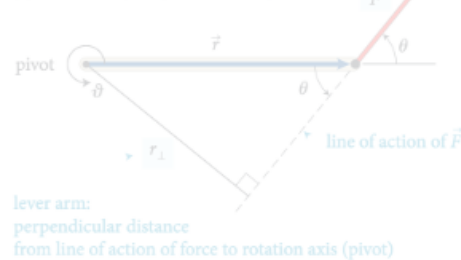
close to 95%!

number of chapters missed before class

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_3 are equal in magnitude, and the magnitude of \vec{F}_2 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

class test results

(b) Multiply magnitude of \vec{F} by r_{\perp} .

lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the right end of the rod and find that the sum of the torques is also zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

every student prepared for every class

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

It is important to note that... 2

This reminds me of when you...

To me is a...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

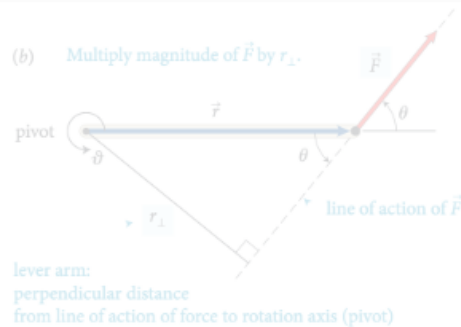
Does torque have the s... 3

I don't understand how this combination of... Oct 20 12:09 am

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

Enter your comment or question and press Enter

(b) Multiply magnitude of \vec{F} by r_{\perp} .

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

Let's do a live demo together

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is $\tau = r \times F$, with r being the level arm distance and F being force. We know that force is a vector vector from previous chapters, and in regards to " r " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

On the very left, we see th...

It's interesting that the white ...

Is the reference frame i... 2

How does force affect ... 2

I was curious about this, t... 3

I understand partially w... 3

In this class, we always emp...

The part before this wa... 2

The extended free-body d... 4

This just means the net... 3

I don't understand why ... 3

is important to note that... 2

This reminds me of when we ...

Torque is the ability of a forc...

The type of diagram to use d...

It sounds like it is sayin... 3

So then do we have a p... 5

Since torque is the cross pro...

The right-hand rule can al... 3

I don't understand how ... 3

Orientation-based descriptio...

I don't really understand... 2

How small is small? As ... 3

I think it would be slightly ...

While I believe I underst... 3

(a) The change in rotationa...

As we saw earlier in the chap...

Objects executing motion ar...

Generally, for rotating bod... 2

Does torque have the s... 3

- sign on to <http://app.perusall.com>
- enter access code **MAZUR-xxxx**
- click on "Chapter 1"
- read (and pose, or answer, questions)

76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating how forces and energy affect an object's motion. The experiments we carry out studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

4.1 Friction

Picture a block of wood sitting motionless on a smooth horizontal surface. If you push the block, it starts moving. But if you stop pushing, the block eventually comes to rest. The smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday experience: a hockey puck slides easily on ice but not on a road. Figure 4.1 shows a velocity-versus-time graph for a wooden block that is sliding on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice is hardly observable. The block slides easily over ice because the friction is so small. The friction is larger on the other two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



You may wonder whether it is possible to make surfaces that are frictionless. In fact, it is not possible to make a perfectly frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, the track's levelness is not appreciably affected by friction.

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

(b) Multiply magnitude of \vec{F} by r_{\perp} .

lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

- virtually 100% completion of assignments
- improved use of class time

CONCEPTS

action of the force and the lever arm distance. So, the torque caused by the force \vec{F} about the pivot is the product of the magnitude of the force and its lever arm distance; it can be written equivalently as rF_{\perp} and as $r_{\perp}F$.

Like other rotational quantities, torque carries a sign that depends on the choice of direction for increasing θ . In Figure 12.4, for example, the torque caused by \vec{F}_1 about the pivot is positive, while the torque caused by \vec{F}_2 is negative. The sum of the two torques about the pivot is then $r_1F_1 + (-r_2F_2)$. As we've seen, the two torques are equal in magnitude when the rod is balanced, and so the sum of the torques is zero. When the sum of the torques is not zero, the rod's rotational acceleration is nonzero, and so its rotational velocity and angular momentum change.

In the situations depicted in Figures 12.4 and 12.5 we used the pivot to calculate the lever arm distances. This is a natural choice because that is the point about which the object under consideration is free to rotate. However, torques also play a role for stationary objects that are suspended or supported at several different points and that are not free to rotate—for example, a plank or bridge supported at either end. To determine what reference point to use in such cases, complete the following exercise.

Exercise 12.1 Reference point

Consider again the rod in Figure 12.4. Calculate the sum of the torques about the left end of the rod.

SOLUTION I begin by making a sketch of the rod and the three forces exerted on it, showing their points of application on the rod (Figure 12.6).

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.

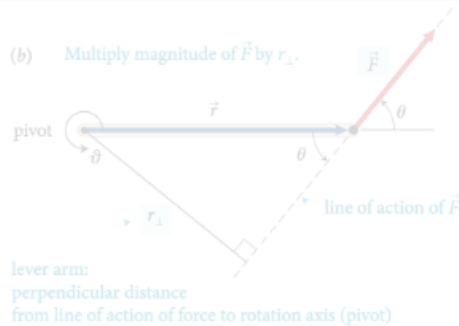


12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

(b) Multiply magnitude of \vec{F} by r_{\perp} .



- virtually 100% completion of assignments
- improved use of class time

CONCEPTS

action of the force and the lever arm distance. So, the torque caused by the force \vec{F} about the pivot is the product of the magnitude of the force and its lever arm distance; it can be written equivalently as rF_{\perp} and as $r_{\perp}F$.

Like other rotational quantities, torque carries a sign that depends on the choice of direction for increasing θ . In Figure 12.4, for example, the torque caused by \vec{F}_1 about the pivot is positive, while the torque caused by \vec{F}_2 is negative. The sum of the two torques about the pivot is then $r_1F_1 + (-r_2F_2)$. As we've seen, the two torques are equal in magnitude when the rod is balanced, and so the sum of the torques is zero. When the sum of the torques is not zero, the rod's rotational acceleration is nonzero, and so its rotational velocity and angular momentum change.

In the situations depicted in Figures 12.4 and 12.5 we used the pivot to calculate the lever arm distances. This is a natural choice because that is the point about which the object under consideration is free to rotate. However, torques also play a role for stationary objects that are suspended or supported at several different points that are not free to rotate. For example, a person can stand on a seesaw at either end. To determine what reference point to use in such cases, complete the following exercise.

Exercise 12.1 Reference point

Consider again the rod in Figure 12.4. Calculate the sum of the torques about the left end of the rod.

SOLUTION I begin by making a sketch of the rod and the three forces exerted on it, showing their points of application on the rod (Figure 12.6).

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$. This is the same result we obtained for the torques about the pivot, and so the sum of

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. This result is true for any stationary rod that is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.

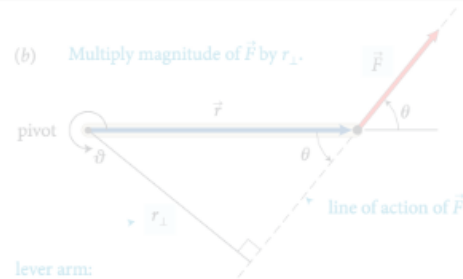
Consider a seesaw that is pivoted at its center and is at rest on the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

all at no cost & without additional instructor effort!

(b) Multiply magnitude of \vec{F} by r_{\perp} .



lever arm:
perpendicular distance
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be written equivalently as rF_{\perp} and as $r_{\perp}F$.

Like other rotational quantities, torque carries a sign that depends on the choice of direction for increasing θ . In Figure 12.4, for example, the torque caused by \vec{F}_1 about the pivot tends to rotate the rod in the direction of increasing θ and so is positive; the torque caused by \vec{F}_2 is negative. The sum of the two torques about the pivot is then $r_1F_1 + (-r_2F_2)$. As we've seen, the two torques are in magnitude, and the sum of the two torques is zero. The rod's rotational acceleration is zero, and so its rotational velocity and angular momentum change.

In the situations depicted in Figures 12.4 and 12.5 we used the pivot to calculate the lever arm distances. This is a natural choice because that is the point about which the object under consideration is free to rotate. However, torques also play a role for stationary objects that are suspended or supported at several different points and that are not free to rotate—for example, a plank or bridge supported at either end. To determine what reference point to use in such cases, complete the following exercise.

Exercise 12.1 Reference point

Consider again the rod in Figure 12.4. Calculate the sum of the torques about the left end of the rod.

SOLUTION I begin by making a sketch of the rod and the three forces exerted on it, showing their points of application on the rod (Figure 12.6).

reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force \vec{F}_1 to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation, \vec{F}_2 causes a negative torque about the left end of the rod; the force \vec{F}_{pr} exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of \vec{F}_2 about the left end of the rod is $r_1 + r_2$; that of \vec{F}_{pr} is r_1 . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces \vec{F}_1 and \vec{F}_2 . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is $(F_1 + F_2)r_1 - (F_1 + F_2)(r_1 + r_2) = 0$. The sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

The sum of the torques about any point is zero. This is a useful result, and it is often used to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



12.2 In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces \vec{F}_1 and \vec{F}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Force \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

follow up questions?
support@perusall.com