Teaching Physics, Conservation Laws First





Teaching Physics, Conservation Laws First





Warsaw, Poland, 27 October

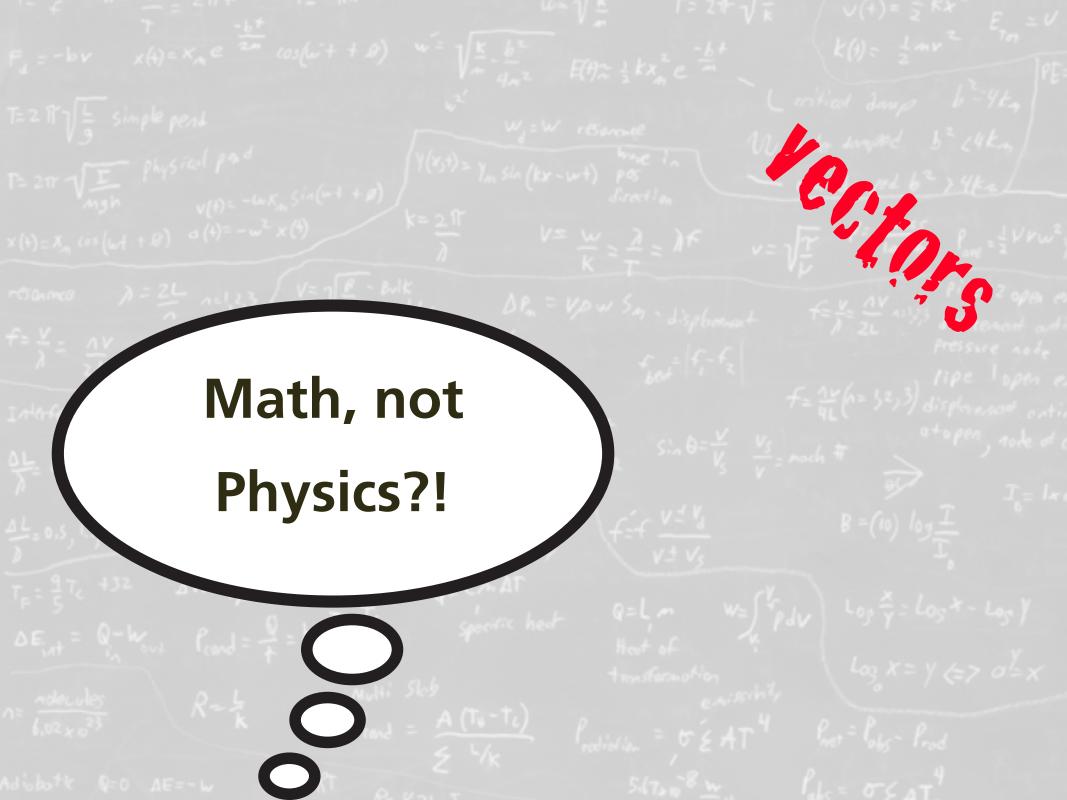


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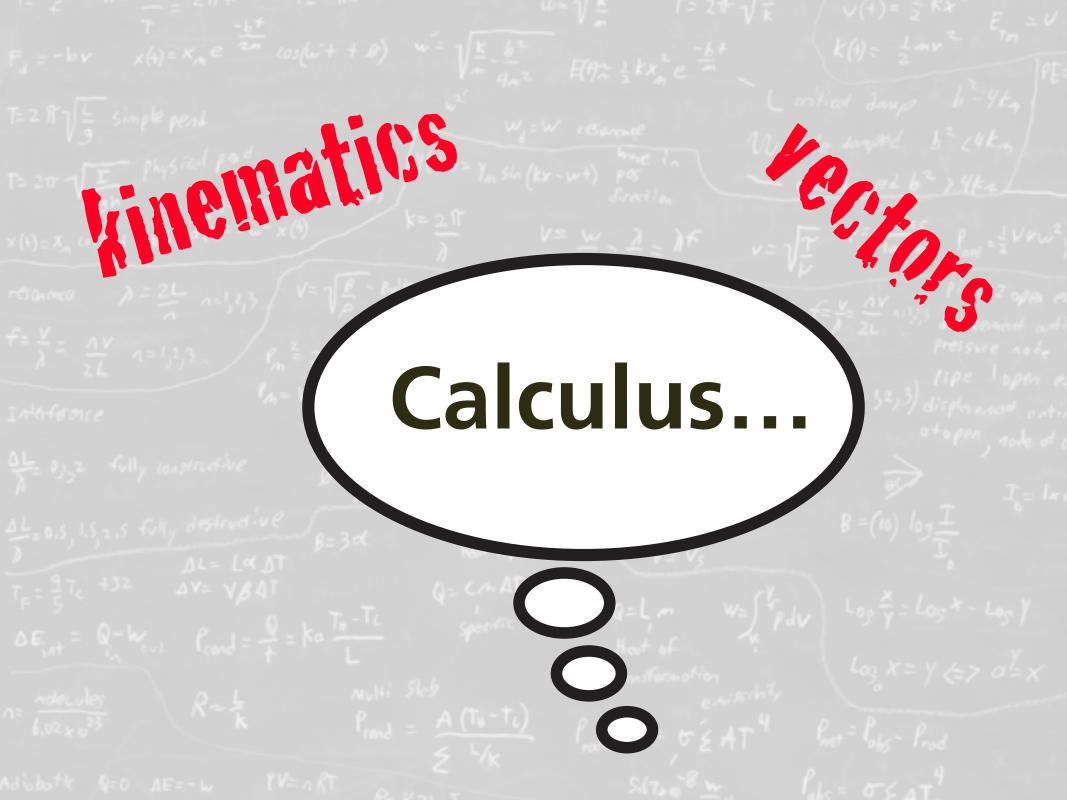
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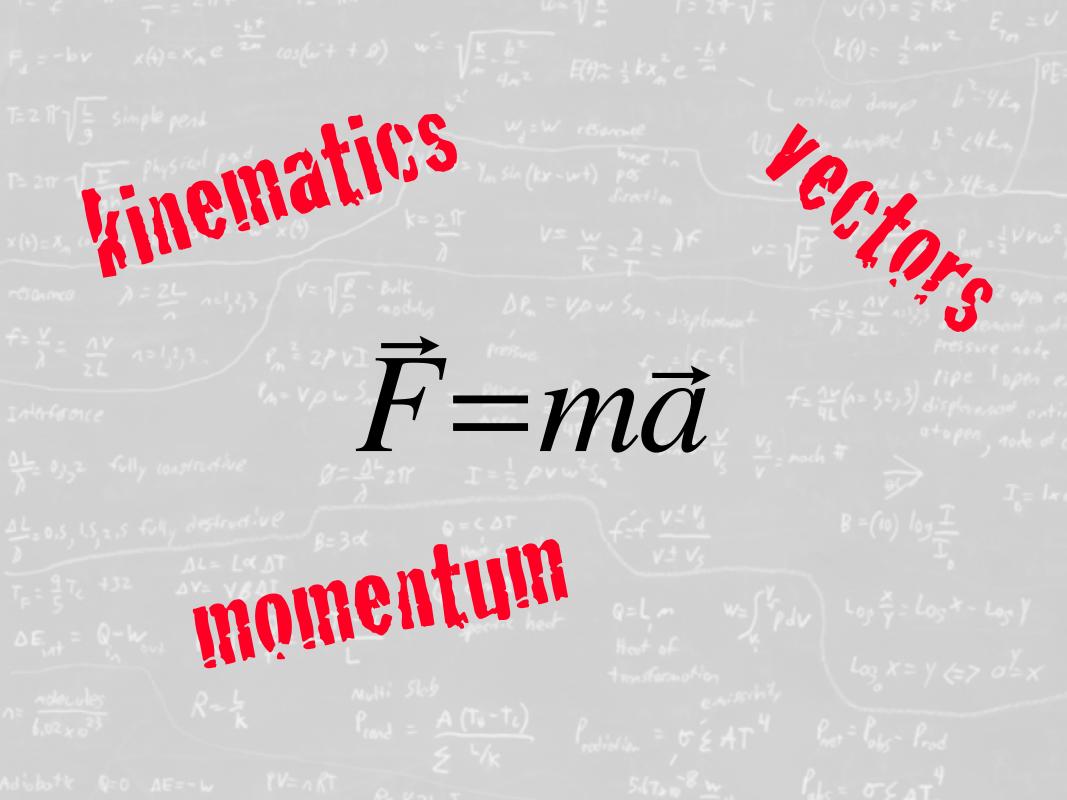
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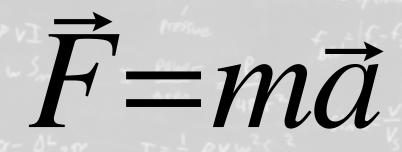


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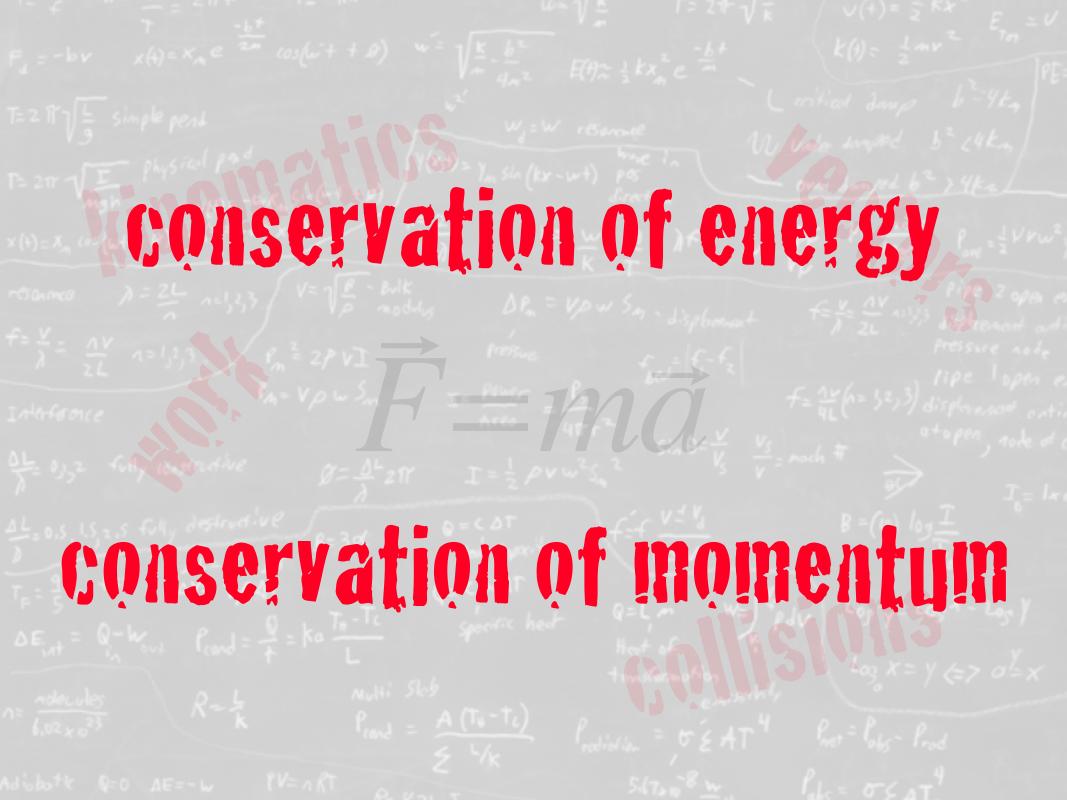
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conservation of energy

Just algebra!

conservation of momentum

conservation of energy

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The historical approach

- Newton's laws
- Collisions
- Momentum (and conservation)
- Work and energy
- Conservation of energy

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Ernst Mach (1838–1916)

- Collisions
- COLLEGE PHYSICS
- Conservation of momentum
- Newton's laws
- Work and energy
- Conservation of energy

Valume 1

er A. Freedman Todd G. Ruskell hilip R. Kesten David L. Tauck

Ernst Mach (1838-1916)

- Collisions (experimental)
- Conservation of momentum (experimental)
- Newton's laws
- Work and energy
- Conservation of energy

er A. Freedman Todd G. Ruskell hilip R. Kesten David L. Tauck

Halliday / Resnick / Walker
PHYSICS

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COLLEGE PHYSICS

wouldn't it be nice if we could start simple?

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PHYSICS FOR SCIENTISTS AND ENGINEERS

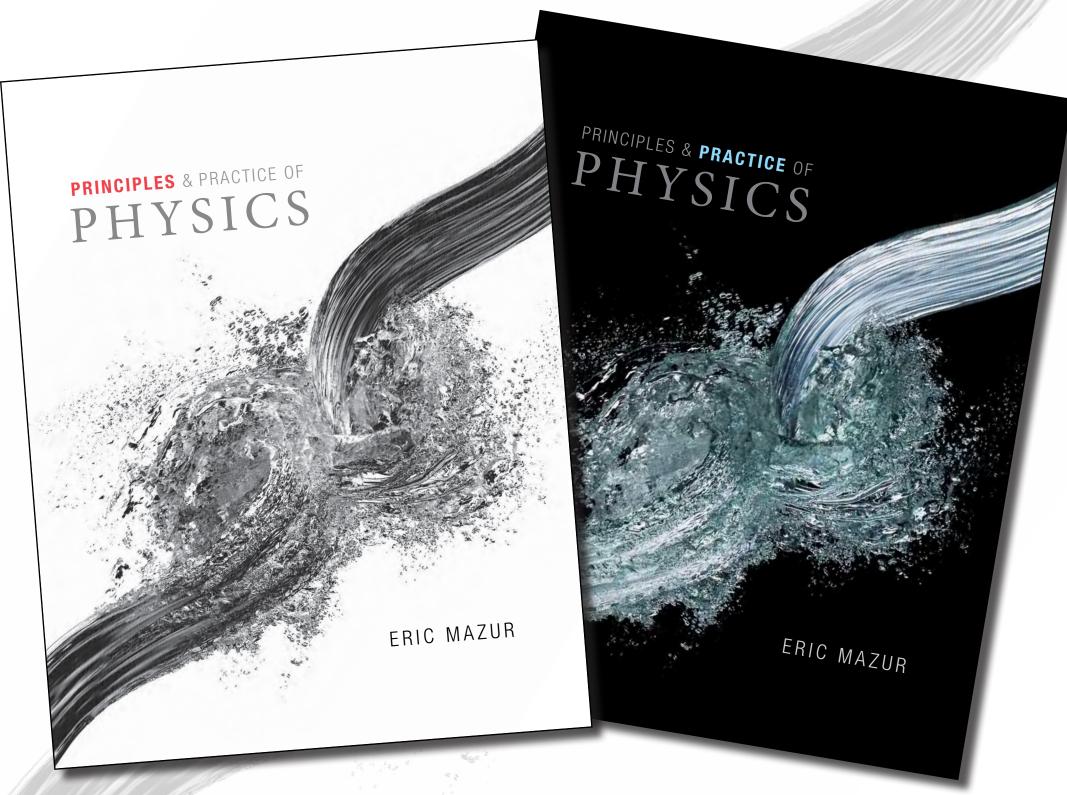
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Volume 1

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we can!



PRINCIPLES & PRACTICE OF

- Conservation of momentum
 - Conservation of energy
 - Interactions
 - Force
 - Work

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PRINCIPLES & PRACTICE OF

- Conservation of momentum (experimental)
 - Conservation of energy (experimental)
 - Interactions
 - Force
 - Work

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PRINCIPLES & PRACTICE OF

- Conservation of momentum (experimental)
- Conservation of energy
- Interactions
- Force
- Work

What about engineers?

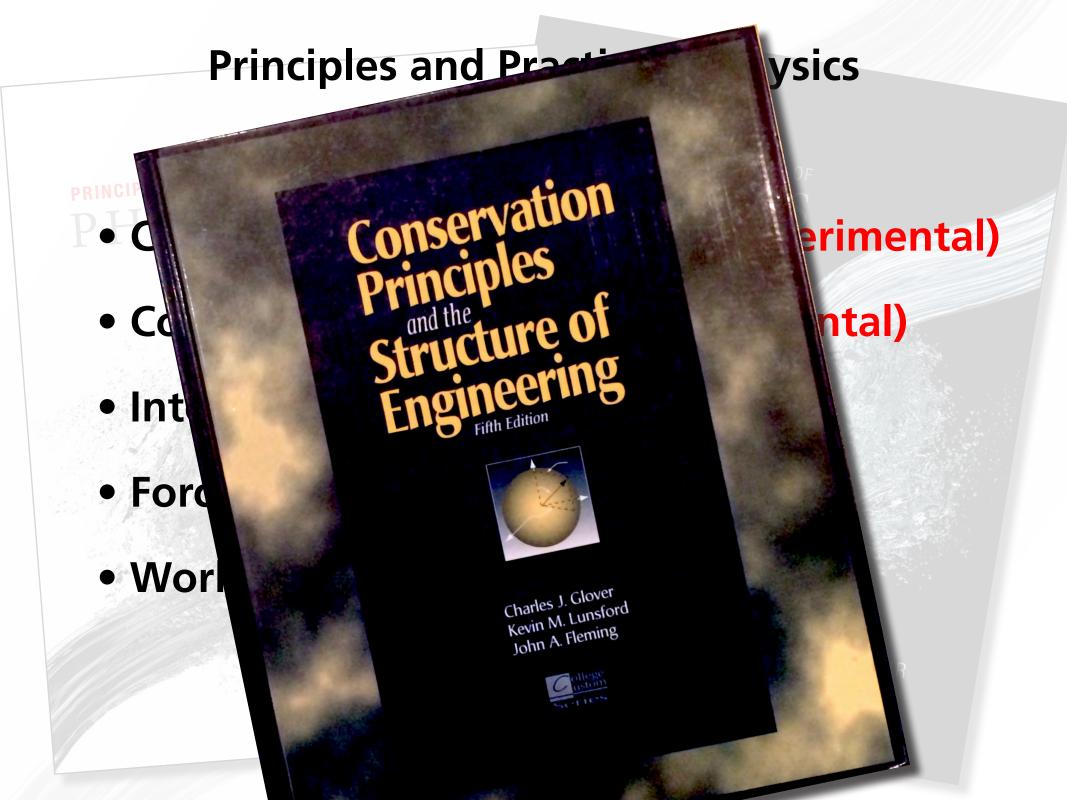
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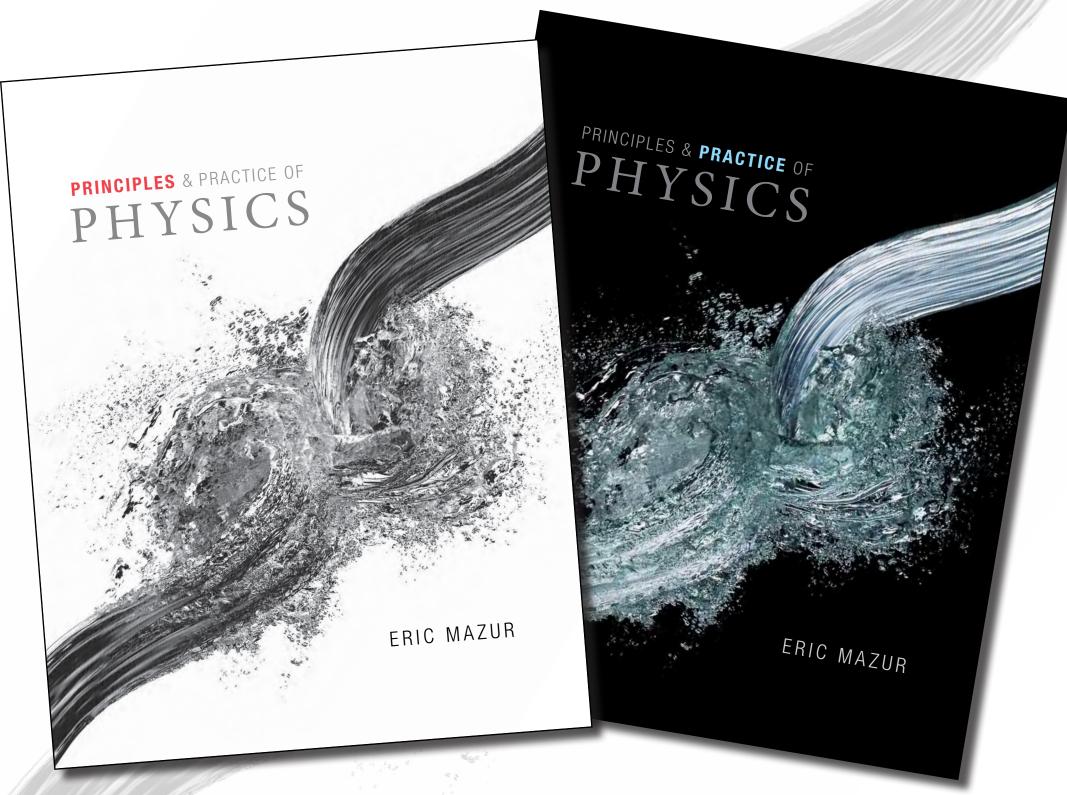
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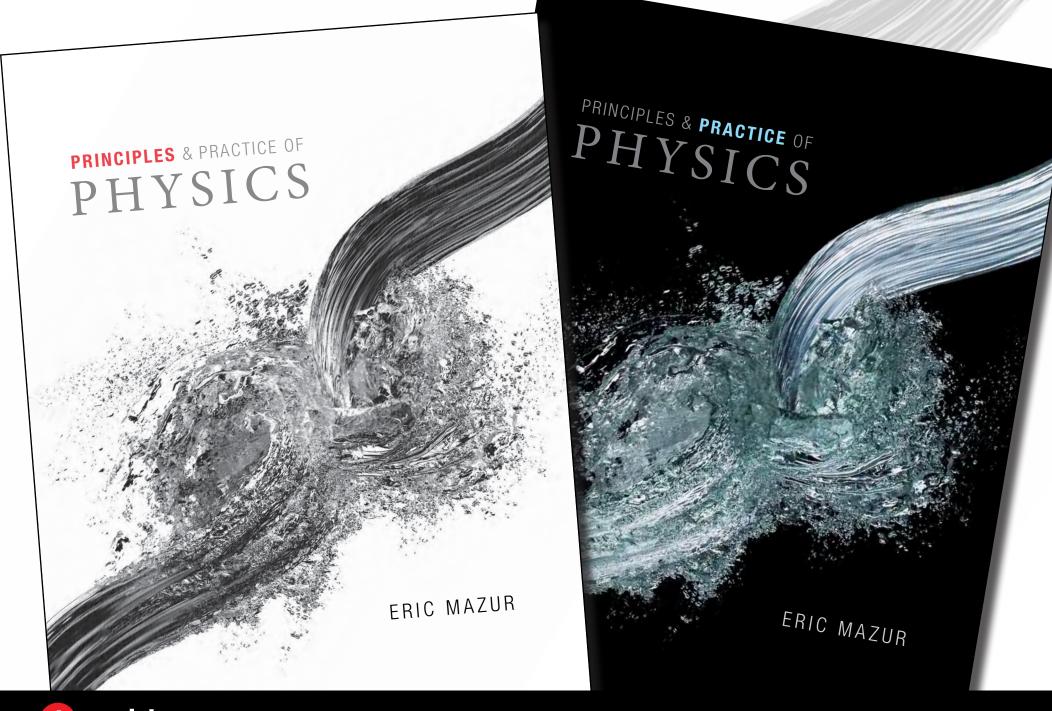
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 - Work

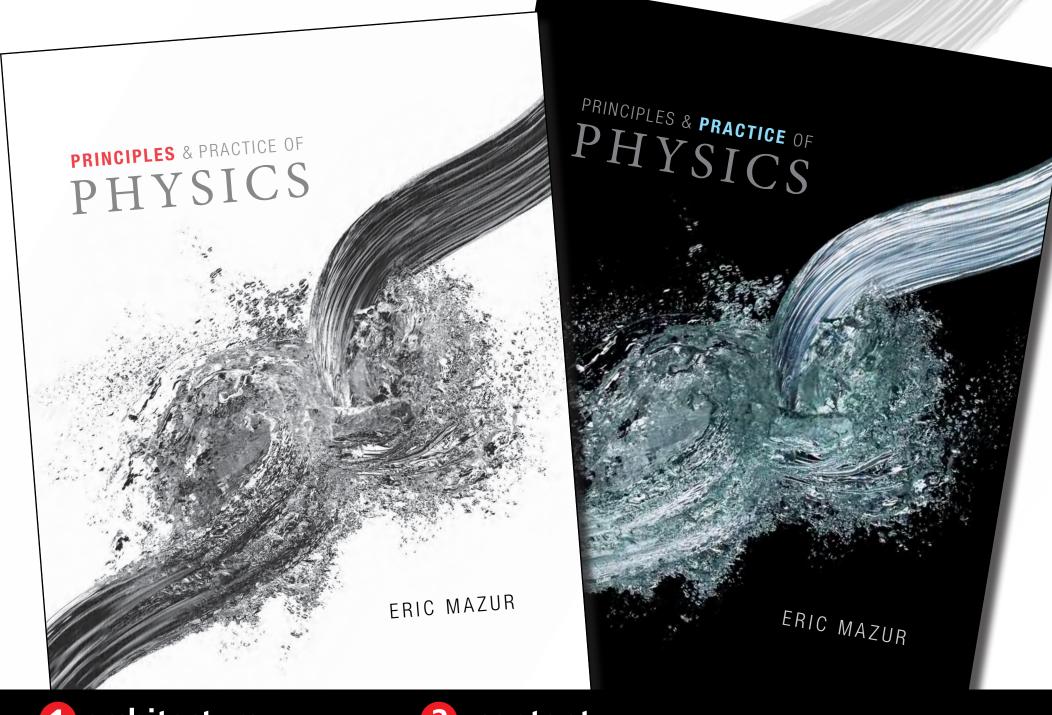
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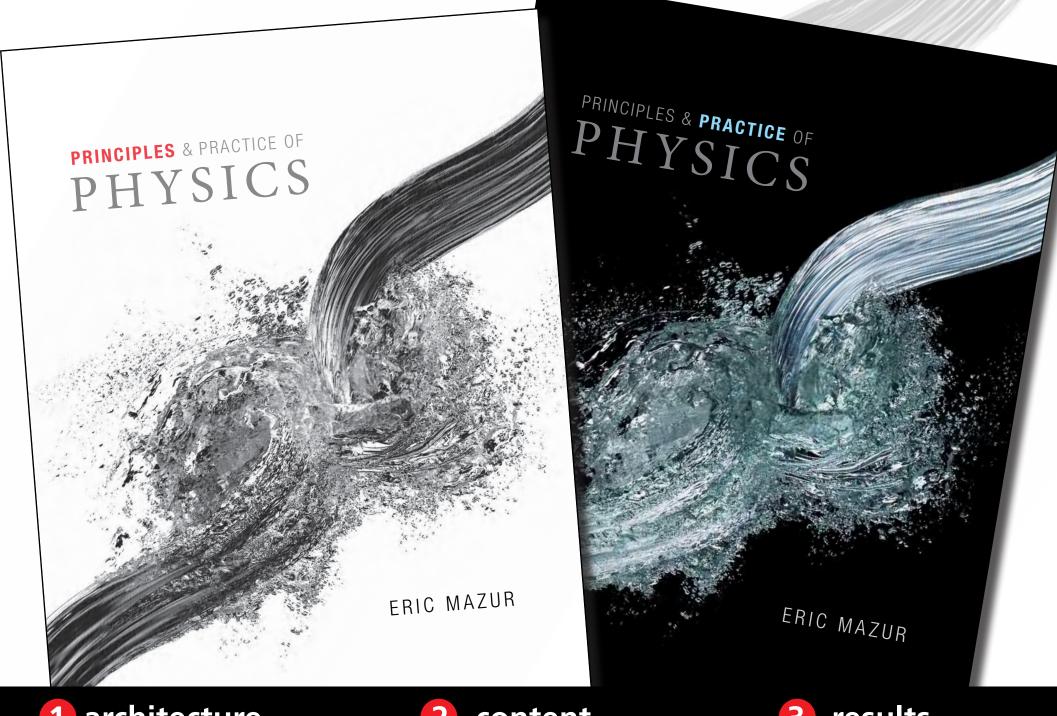






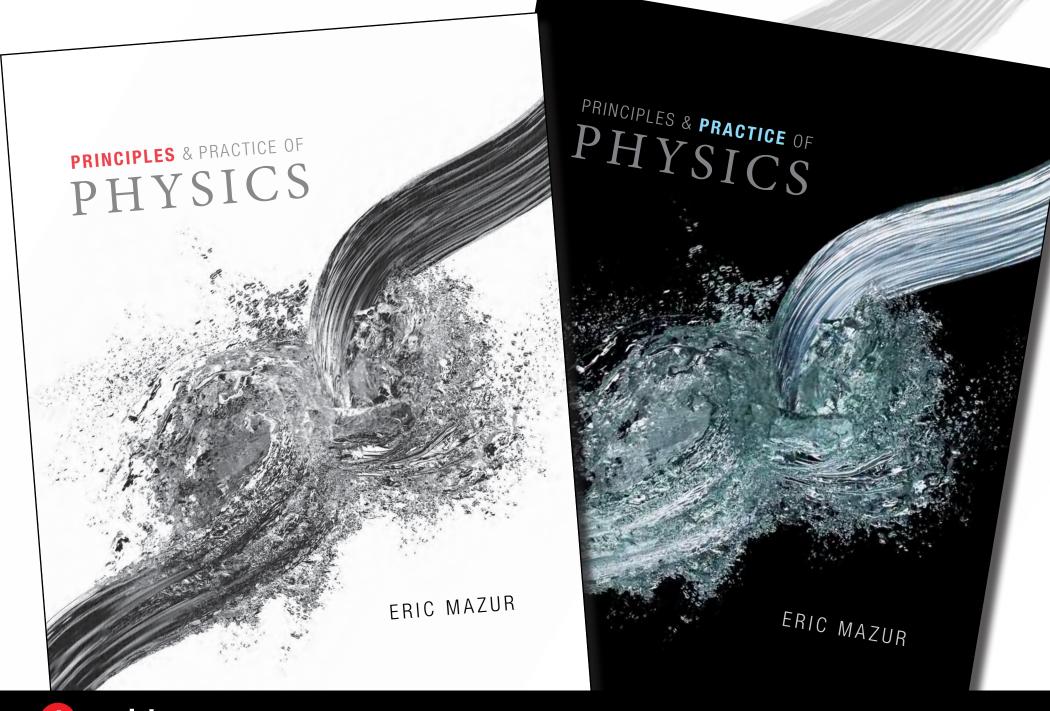


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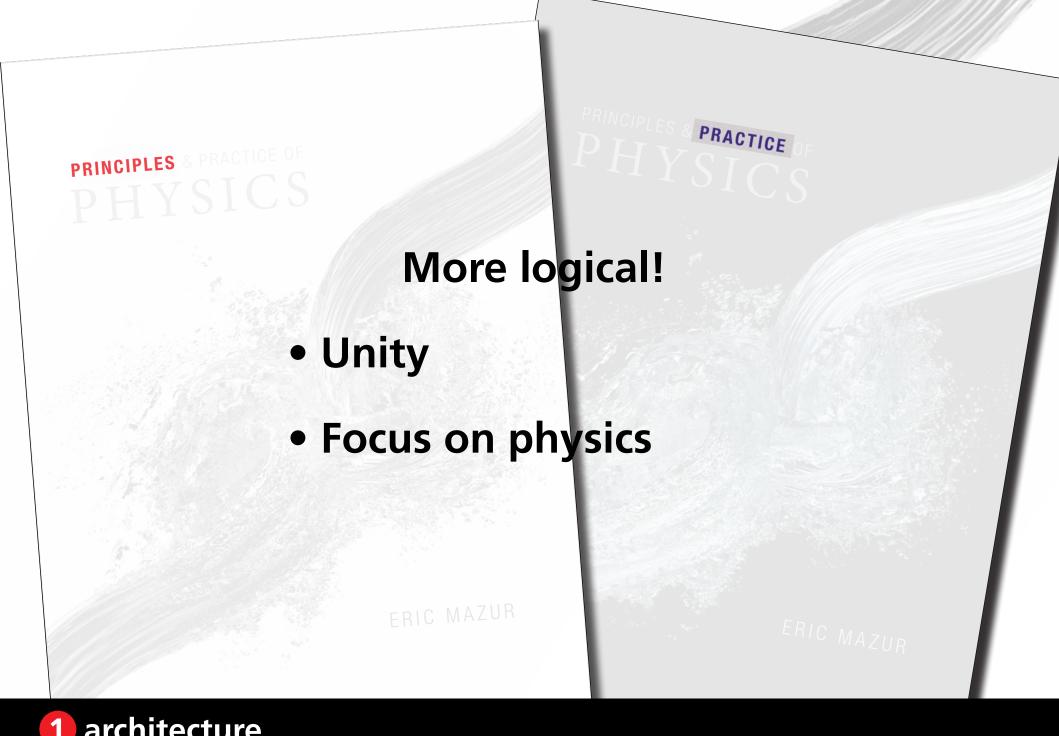
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why 2 books?







PRINCIPLES & PRACTICE OF PHYSICS

PRINCIPLES & PRACTICE OF

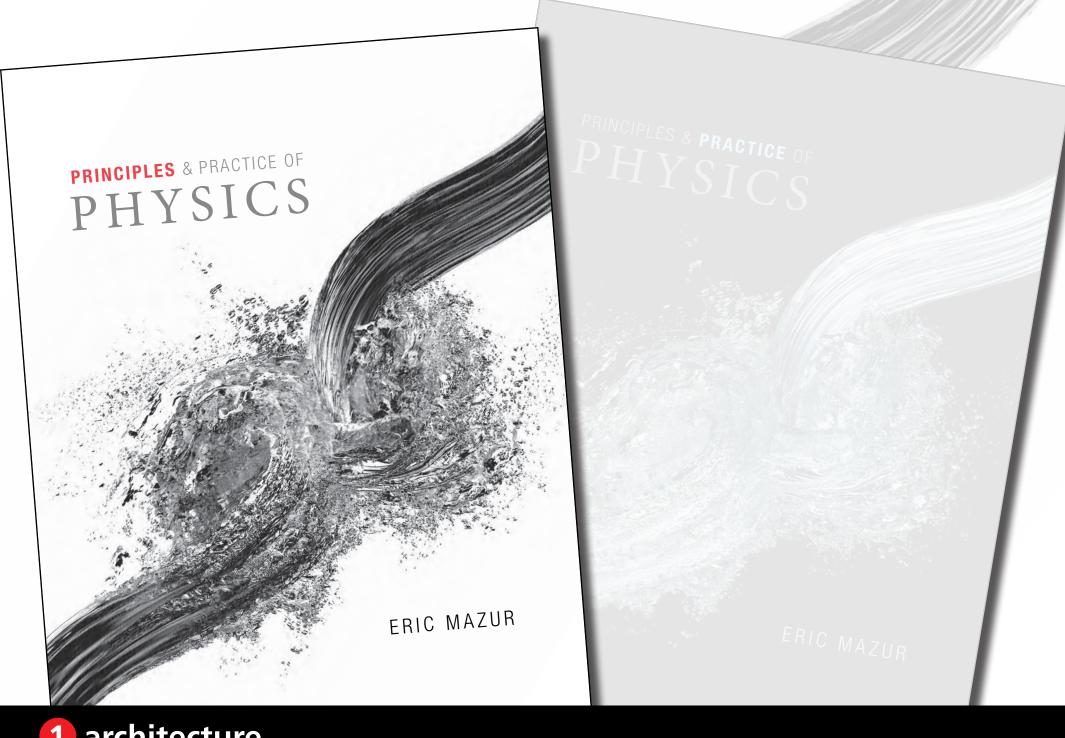
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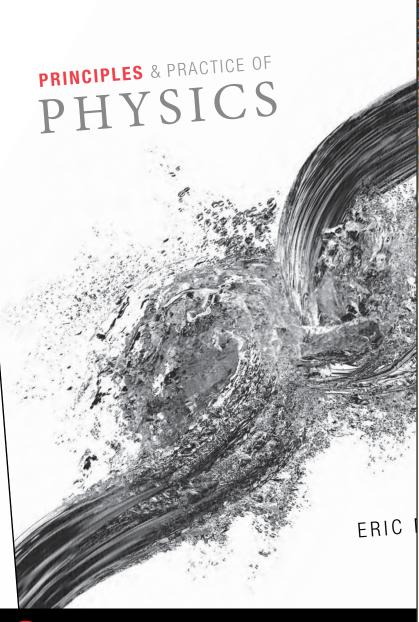
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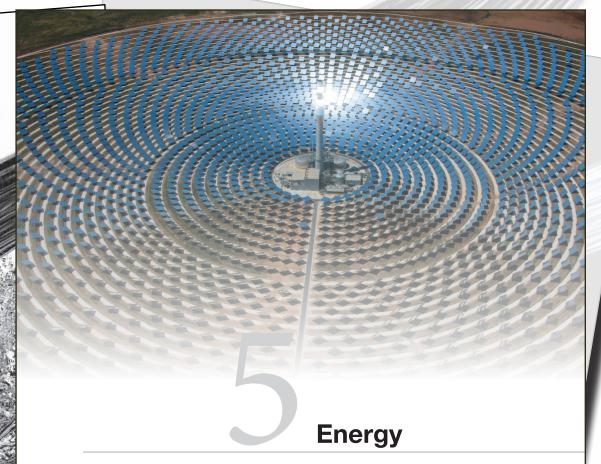
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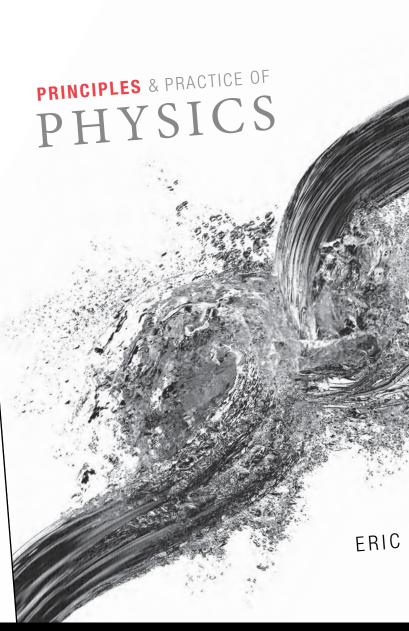


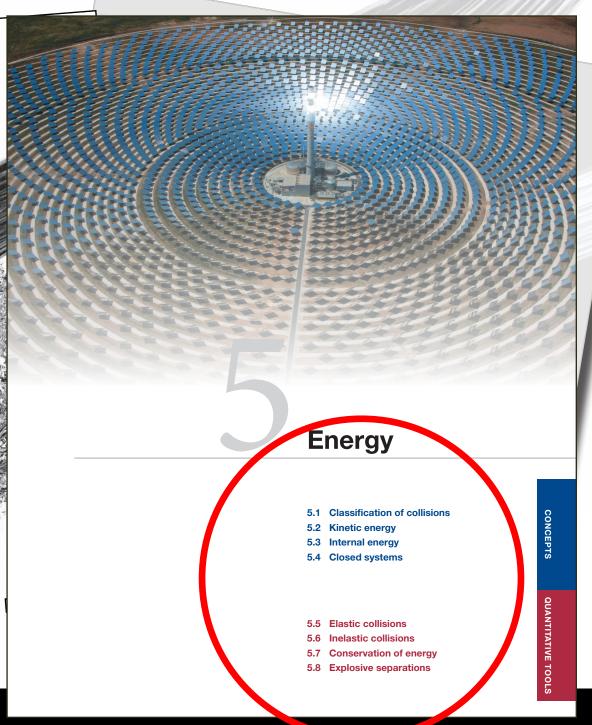


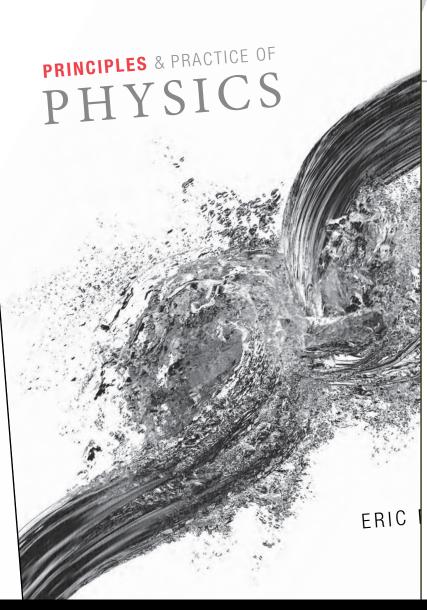




- 5.1 Classification of collisions
- 5.2 Kinetic energy
- 5.3 Internal energy
- 5.4 Closed systems
- 5.5 Elastic collisions
- 5.6 Inelastic collisions
- 5.7 Conservation of energy
- 5.8 Explosive separations



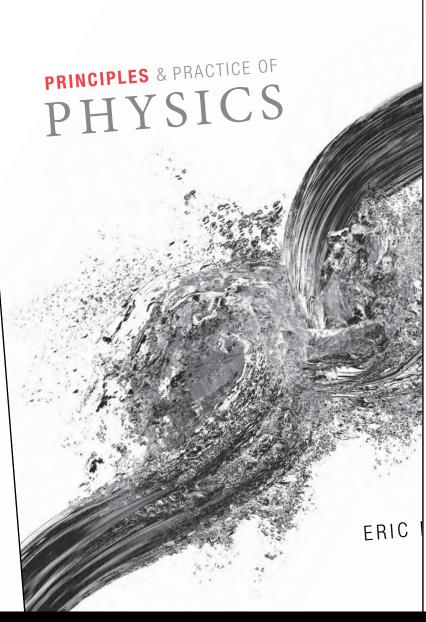




Energy

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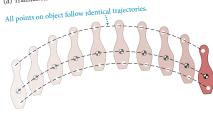
CONCEPTS

The motion we have been dealing with so far in this text is called translational motion (Figure 11.1a). This type of motion involves no change in an object's orientation; in other words, all the particles in the object move along identical parallel trajectories. During rotational motion, which we begin to study in this chapter, the orientation of the object changes, and the particles in an object follow different circular paths centered on a straight line called the axis of rotation (Figure 11.1b). Generally, the motion of rigid objects is a combination of these two types of motion (Figure 11.1c), but as we shall see in Chapter 12 this combined motion can be broken down into translational and rotational parts that can be analyzed separately. Because we already know how to describe translational motion, knowing how to describe rotational motion will complete our description of the motion of rigid objects.

As Figure 11.1*b* shows, each particle in a rotating object traces out a circular path, moving in what we call circular

Figure 11.1 Translational and rotational motion of a rigid object.

(a) Translational motion

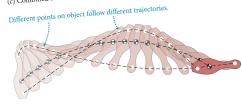


(b) Rotational motion

All points on object trace circles centered on axis of rotation.



(c) Combined translation and rotation

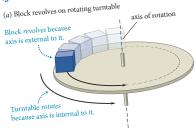


motion. We therefore begin our analysis of rotational motion by describing circular motion. Circular motion occurs all around us. A speck of dust stuck to a spinning CD, a stone being whirled around on a string, a person on a Ferris wheel—all travel along the perimeter of a circle, repeating their motion over and over. Circular motion takes place in a plane, and so in principle we have already developed all the tools required to describe it. To describe circular and rotational motion we shall follow an approach that is analogous to the one we followed for the description of translational motion. Exploiting this analogy, we can then use the same results and insights gained in earlier chapters to introduce a third conservation law.

11.1 Circular motion at constant speed

Figure 11.2 shows two examples of circular motion: a block dragged along a circle by a rotating turntable and a puck constrained by a string to move in a circle. The block and puck are said to revolve around the vertical axis through the center of each circular path. Note that the axis about which they revolve is external to the block and puck and perpendicular to the plane of rotation. This is the definition of revolve—to move in circular motion around an external center. Objects that turn about an internal axis, such as the turntable in Figure 11.2a, are said to rotate. These two types of motion are closely related because a rotating object can be considered as a system of an enormous number of particles, each revolving around the axis of rotation.

Figure 11.2 Examples of circular motion.



(b) Tethered puck revolves on air table



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11.1 Circular motion at constant speed

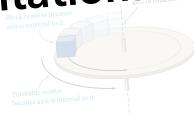
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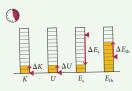


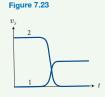


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Self-quiz

- 1. Two carts are about to collide head-on on a track. The inertia of cart 1 is greater than the inertia of cart 2, and the collision is elastic. The speed of cart 1 before the collision is higher than the speed of cart 2 before the collision. (a) Which cart experiences the greater acceleration during the collision? (b) Which cart has the greater change in momentum due to the collision? (c) Which cart has the greater change in kinetic energy during the collision?
- 2. Which of the following deformations are reversible and which are irreversible: (a) the deformation of a tennis ball against a racquet, (b) the deformation of a car fender during a traffic accident, (c) the deformation of a balloon as it is blown up, (d) the deformation of fresh snow as you walk through it?
- 3. Translate the kinetic energy graph in Figure 7.2 into three sets of energy bars: before the collision, during the collision, and after the collision. In each set, include a bar for K_1 , a bar for K_2 , and a bar for the internal energy of the system, and assume that the system is closed.
- 4. Describe a scenario to fit the energy bars shown in Figure 7.22. What happens during the interaction?





5. Describe a scenario to fit the velocity-versus-time curves for two colliding objects shown in Figure 7.23. What happens to the initial energy of the system of colliding objects during the interaction?

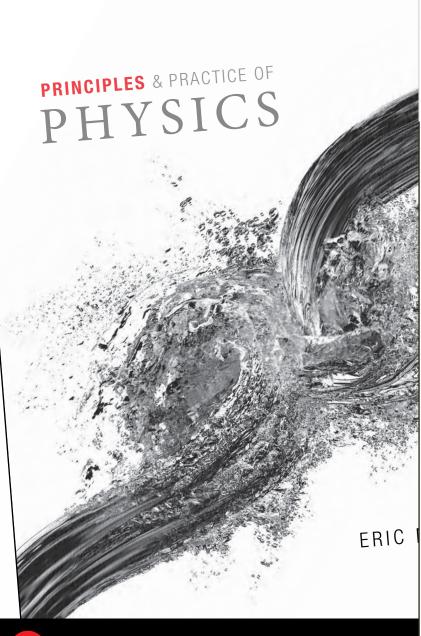
Answers

- 1. (a) The cart with the smaller inertia experiences the greater acceleration (see Figure 7.2). (b) The magnitude of $\Delta \vec{p}_1$ is the same as the magnitude of $\Delta \vec{p}_2$, but the changes are in opposite directions because the momentum of the system does not change during the collision. (c) $|\Delta K_1|=|\Delta K_2|$, but the changes are opposite in sign because the kinetic energy of the system before the elastic collision has to be the same as the kinetic energy of the system afterward.
- $\textbf{2.} \ \ (a) \ \text{Reversible}. \ \text{The ball returns to its original shape}. \ (b) \ \text{Irreversible}. \ \text{The fender remains crumpled}. \ (c) \ \text{Irreversible}.$ The balloon does not completely return to its original shape after deflation. (d) Irreversible. Your footprints
- **3.** See **Figure 7.24**. Before the collision $K_1 = 0$, K_2 is maximal, and $E_{int} = 0$; during the collision K_1 , K_2 , and E_{int} are all about one-third of the initial value of K_1 ; after the collision K_1 is about 7/8 of the initial value of K_1 , K_2 is about 1/8 of the initial value of K_1 , and $E_{\rm int}=0$. Because the system is closed, its energy is constant, which means the sum of the three bars is always the same.

after during K₁ K₂ E_{int}

- 4. During the interaction, eight units of source energy is converted to two units of kinetic energy, two units of potential
- energy, and four units of thermal energy. One possible scenario is the vertical launching of a ball. Consider the system comprising you, the ball, and Earth from just before the ball is launched until after it has traveled some $distance\ upward.\ The\ source\ energy\ goes\ down\ (you\ exert\ some\ effort), thermal\ energy\ goes\ up\ (in\ the\ process$ of exerting effort you heat up), kinetic energy goes up (the ball was at rest before the launch), and so does potential energy (the distance between the ground and the ball increases).
- 5. The graph represents an inelastic collision because the relative velocity of the two objects decreases to about half its initial value. In order for the momentum of the system to remain constant, the inertia of object 1 must be twice that of object 2. Possible scenario: Object 2, inertia m, collides inelastically with object 1, inertia 2m. The collision brings object 2 to rest and sets object 1 in motion. The interaction converts the initial kinetic energy of object 2 to kinetic energy of cart 1 and to thermal energy and/or incoherent configuration energy of both carts.

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Energy

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QUANTITATIVE TOOLS

6.5 Galilean relativity

Consider two observers, A and B, moving at constant velocity relative to each other. Suppose they observe the same event and describe it relative to their respective reference frames and clocks (Figure 6.13). Let the origins of the two observers' reference frames coincide at t = 0 (Figure 6.13*a*). Observer A sees the event as happening at position \vec{r}_{Ae} at clock reading t_{Ae} (Figure 6.13b).* Observer B sees the event at position \vec{r}_{Be} at clock reading t_{Be} . What is the relationship between these clock readings and positions?

If, as we discussed in Chapter 1, we assume time is absolute—the same everywhere—and if the two observers have synchronized their (identical) clocks, they both observe the event at the same clock readings, which means

$$t_{Ae} = t_{Be}. ag{6.1}$$

Because the clock readings of the two observers always agree, we can omit the subscripts referring to the reference frames:

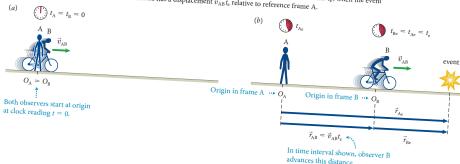
$$t_{\rm A} = t_{\rm B} = t. \tag{6.2}$$

From Figure 6.13 we see that the position \vec{r}_{AB} of observer B in reference frame A at instant t_e is equal to B's displacement over the time interval $\Delta t = t_e - 0 = t_e$, and so $\vec{r}_{AB} = \vec{v}_{AB} t_e$ because B moves at constant velocity

$$\vec{r}_{Ae} = \vec{r}_{AB} + \vec{r}_{Be} = \vec{v}_{AB} t_e + \vec{r}_{Be}.$$
 (6.3)

Equations 6.2 and 6.3 allow us to relate event data collected in one reference frame to data on the same event e collected in a reference frame that moves at constant velocity relative to the first one (neither of these has to be at rest relative to Earth, but their origins must coincide at t=0). To this end we rewrite these equations so that they give the values of time and position in reference frame B

Figure 6.13 Two observers moving relative to each other observe the same event. Observer B moves at constant velocity \vec{v}_{AB} relative to observer A. (a) The origins O of the two reference frames overlap at instant t = 0. (b) At instant t_e , when the event occurs, the origin of observer B's reference frame has a displacement $\vec{v}_{AB}t_{\rm e}$ relative to reference frame A.



^{*}Remember our subscript form: The capital letter refers to the reference frame; the lowercase e is for "event." Thus the vector \vec{r}_{Ae} represents observer \underline{A} 's measurement of the position at which the event

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where—and if the two observers have synchronized their (identical) clocks, they both observe the event at the same clock readings, which means

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$$t_{\rm A} = t_{\rm B} = t. \tag{6.2}$$

From Figure 6 inderso pointings to $\Delta t = t_r - 0 = t_r$, and so $r_{AR} = v_{AR} t_r$ because moves at constant velocity σ

$$\vec{r}_{Ae} = \vec{r}_{AB} + \vec{r}_{Be} = \vec{v}_{AB} t_e + \vec{r}_{Be}.$$
 (63)

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CONCEPTS

(b) From Figure 10.18 I see that $\tan \theta = |F_{\text{sp}x}^{\text{c}}|/|F_{\text{sp}y}^{\text{c}}|$. For $\theta < 45^{\circ}$, tan $\theta < 1$, and so $|F_{\rm sp}^{\rm c}| < |F_{\rm spy}^{\rm c}|$. Because $|F_{\rm spy}^{\rm c}| = F_{\rm Ep}^{\rm G}$ and $|F_{\text{sp.x}}^{\text{c}}| = F_{\text{rp}}^{\text{c}}$, I find that for $\theta < 45^{\circ}$, $F_{\text{rp}}^{\text{c}} < F_{\text{Ep}}^{G}$. When $\theta > 45^{\circ}$, tan $\theta > 1$, and so $|F_{\rm sp.x}^{\rm c}| > |F_{\rm sp.y}^{\rm c}|$ and $F_{\rm rp}^{\rm c} > F_{\rm Ep}^{\rm G}$.

(c) $|\vec{F}_{\text{spy}}^{\text{c}}| = F_{\text{Ep}}^{G}$ and $F_{\text{sp}}^{\text{c}} = \sqrt{(F_{\text{spx}}^{\text{c}})^{2} + (F_{\text{spy}}^{\text{c}})^{2}}$. Therefore, F_{sp}^{c} must always be larger than F_{Ep}^{G} when $\theta \neq 0$.

4 EVALUATE RESULT I know from experience that you have to pull harder to move a swing farther from its equilibrium position, and so my answer to part a makes sense. With regard to part b, when the swing is at rest at 45°, the forces \vec{F}_{rp}^c and \vec{F}_{Ep}^G on your friend make the same angle with the force $F_{\rm sp}^{\rm rc}$, and so $\vec{F}_{\mathrm{rp}}^{\mathrm{c}}$ and $\vec{F}_{\mathrm{Ep}}^{G}$ should be equal in magnitude. The force of gravity is independent of the angle, but the force exerted by the rope increases with increasing angle, and so it makes sense that for angles larger than 45°, $\vec{F}_{\rm rp}^c$ is larger than $\vec{F}_{\rm Ep}^G$. In part c, because the vertical component of the force \vec{F}_{sp}^c exerted by the seat on your friend always has to be equal to the force of gravity, adding a horizontal component makes $\vec{F}_{\rm sp}^{\rm c}$ larger than $\vec{F}_{\rm Ep}^{\rm G}$, as I found.

10.4 You decide to move a heavy file cabinet by sliding it across the floor. You push against the cabinet, but it doesn't budge. Draw a free-body diagram for it.

10.4 Friction

The force that opposes your push on the file cabinet in Checkpoint 10.4—the tangential component of the contact force exerted by the floor on the cabinet—has to do with friction. If the floor were very slick or if the cabinet had casters, there would be little friction and your push would easily move the cabinet. Instead, you have to lean against it with all your strength until, with a jerk, it suddenly begins to slide. Once you get the cabinet moving, you must keep pushing to keep it in motion. If you stop pushing, friction stops the motion.

10.5 (a) Suppose you push the file cabinet just enough to keep it moving at constant speed. Draw a free-body diagram for the cabinet while it slides at constant speed. (b) Suddenly you stop pushing. Draw a free-body diagram for the file cabinet at

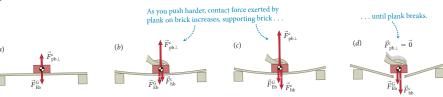
Don't skip Checkpoint 10.5! It will be harder to understand the rest of this section if you haven't thought about

Even though the normal and tangential components of the contact force exerted by the floor on the cabinet belong to the same interaction, they behave differently and are usually treated as two separate forces: the normal component being called the normal force and the tangential component being called the force of friction.

To understand the difference between normal and frictional forces, consider a brick on a horizontal wooden plank supported at both ends (Figure 10.19a). Because the brick is at rest, the normal force $\vec{F}_{pb\perp}^c$ exerted by the plank on it is equal in magnitude to the gravitational force exerted on it. Now imagine using your hand to push down on the brick with a force \vec{F}_{hb}^c . Your downward push increases the total downward force exerted on the brick, and, like a spring under compression, the plank bends until the normal force it exerts on the brick balances the combined downward forces exerted by your hand and by Earth on the brick (Figure 10.19b). As you push down harder, the plank bends more, and the normal force continues to increase (Figure 10.19c) until you exceed the plank's capacity to provide support and it snaps, at which point the normal force suddenly disappears (Figure 10.19d). So, normal forces take on whatever value is required to prevent whatever is pushing down on a surface from moving through that surface up to the breaking point of the supporting material.

Next imagine that instead of pushing down on the brick of Figure 10.19a, you gently push it to the right, as in Figure 10.20. As long as you don't push hard, the brick remains at rest. This tells you that the horizontal forces exerted on the brick add to zero, and so the plank must be exerting on the brick a horizontal frictional force that is equal in magnitude to your push but in the opposite direction. This horizontal force is caused by microscopic bonds between the surfaces in contact. Whenever two objects are placed in contact, such bonds form at the extremities of microscopic bumps on the surfaces of the objects. When you try to slide the surfaces past each other, these tiny bonds prevent sideways motion. As you push the brick to the right, the bumps resist bending and, like microscopic springs, each bump exerts a force to the left. The net effect of all these microscopic forces is to hold the brick in place. As you increase the force of your push, the bumps resist bending more and the tangential component of the contact force grows. This friction exerted by surfaces that are not moving relative to each other is called static friction.

Figure 10.19 A demonstration of the normal force.



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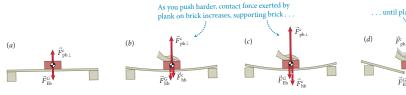
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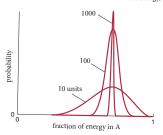
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Figure 19.14 Probability of finding a given fraction of the system's energy in compartment A of the box in Figure 19.13. As the number of energy units increases from 10 to 1000, the probability distribution becomes narrower but remains centered about the mean energy.



basic states available to the system is obtained by multiplying Ω_A by Ω_B : $\Omega = \Omega_A \Omega_B$.

The probability of each macrostate is obtained by dividing Ω , the number of basic states associated with that macrostate, by Ω_{tot} , the number of basic states associated with all macrostates (2.00 \times 10⁷; see Table 19.2). The table shows you that this probability is greatest for the macrostate $E_A = 7$, as you would expect. Given that there are 14 particles in A and six in B, on average each particle has half an energy unit, and so the $E_A = 7$ macrostate corresponds to an equipartitioning of the energy. The curve labeled 10 units in Figure 19.14 shows this probability as a function of the fraction of energy contained in A.

Example 19.6 Probability of macrostates

In Figure 19.13, after a very large number of particle-partition collisions have occurred, what is the probability of finding the system in (a) the macrostate $E_A = 1$ and (b) the macrostate $E_{\Lambda} = 7$?

• GETTING STARTED Because all basic states are equally likely, the probability of finding the system in macrostate $E_{\rm A}$ is equal to the fraction $\Omega/\Omega_{\rm tot}$ where Ω is the number of basic states of the system associated with the macrostate $E_{\rm A}$ and $\Omega_{\rm tot}$ is the total number of basic states associated with all macrostates $(2.00 \times 10^7; Table 19.2).$

2 DEVISE PLAN To find the probability of a given macrostate $E_{\rm A},$ I divide the value of Ω for that macrostate given in Table 19.2 by $\Omega_{\rm tot} = 2.00 \times 10^7$.

3 EXECUTE PLAN (a) For $E_A = 1$, Table 19.2 tells me that $\Omega = 2.80 \times 10^4$. The probability of macrostate $E_A = 1$ is thus $(2.80 \times 10^4)/(2.00 \times 10^7) = 1.40 \times 10^{-3}$

(b) For the macrostate $E_{\rm A}=7,\Omega=4.34\times10^6$. So the probability of this macrostate occurring is $(4.34 \times 10^6)/(2.00 \times 10^7) =$ 2.17×10^{-1} .

4 EVALUATE RESULT My result shows that the macrostate $E_{\scriptscriptstyle A}=7$ is more than 150 times more probable than the macrostate $E_{\rm A}=1$. This makes sense because, as we saw earlier, the macrostate $E_A = 7$ is the equilibrium state for which there is an equipartition of energy.

If we increase the number of energy units in the box of Figure 19.13 to 100 or 1000, the number of basic states grows exponentially, and if we plot the probability of each macrostate as a function of the fraction of energy in A, we obtain the two curves labeled 100 and 1000 in Figure 19.14. Just as we saw in Figure 19.7, the most probable macrostate doesn't change, but the probability peaks much more narrowly around this state. In other words, the most probable macrostate—the equilibrium state—is now even more likely than any other macrostate.

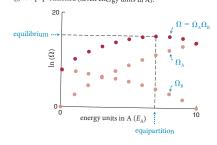
Note that the number of basic states is very large, even with just ten energy units and 20 particles. In a box of volume 1 m³ containing air at atmospheric pressure and room temperature, there are on the order of 1025 particles and 10²⁰ energy units per particle, and so the number of basic states becomes unimaginably large—on the order of ten raised to the power 10²¹! Because the number of basic states is so large, it is more convenient to work with the natural logarithm of that number. As you can see from the rightmost column in Table 19.2, the natural logarithm of the number of basic states is indeed much more manageable.

Figure 19.15 shows how the natural logarithms of Ω_A , Ω_B , and Ω vary with the number of energy units in compartment A in Figure 19.13. As you can see, the natural logarithm of the number of basic states changes much less rapidly than the number of basic states. Note that as $E_{\rm A}$ increases, the number of basic states Ω_A increases. As E_A increases, however, E_B decreases and so $\Omega_{\rm B}$ decreases. The number of basic states Ω is maximum when $E_A = 7$ and $E_B = 3$, representing an equipartition of energy. The most probable macrostate (equilibrium) is achieved when there is equipartition of energy.

19.15 What is the average energy per particle in compartments A and B in Figure 19.13 (a) when there is one energy unit in A and (b) when the system is at equilibrium?

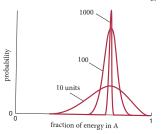
As you can see from Table 19.2, with $E_{\rm A}=1$ the number of basic states for the system (2.80 imes 10 4) is more than 100 times smaller than it is at equilibrium ($E_A = 7$, $\Omega = 4.34 \times 10^6$). Collisions between the particles and the partition redistribute

Figure 19.15 Natural logarithm of the number of basic states for compartment A, for compartment B, and for the two compartments in Figure 19.13 combined. The number of basic states is maximal when the energy is equipartitioned (seven energy units in A).



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3 EXECUTE PLAN (a) For $E_A = 1$, Table 19.2 tells me that $\Omega = 2.80 \times 10^4$. The probability of macrostate $E_A = 1$ is thus $(2.80 \times 10^4)/(2.00 \times 10^7) = 1.40 \times 10^{-3}$. ✔

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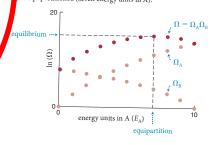
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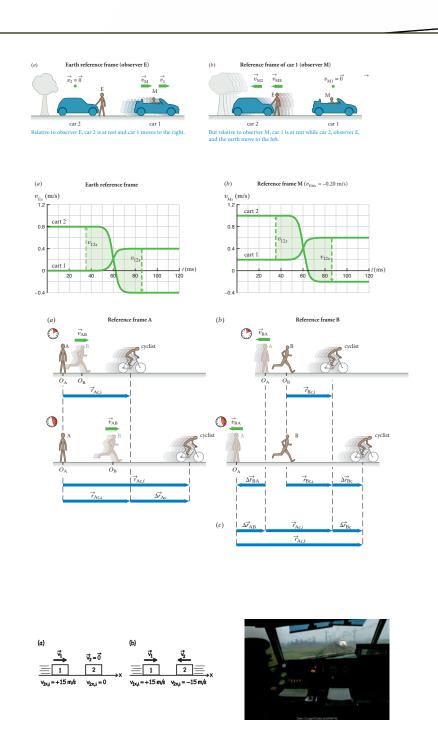
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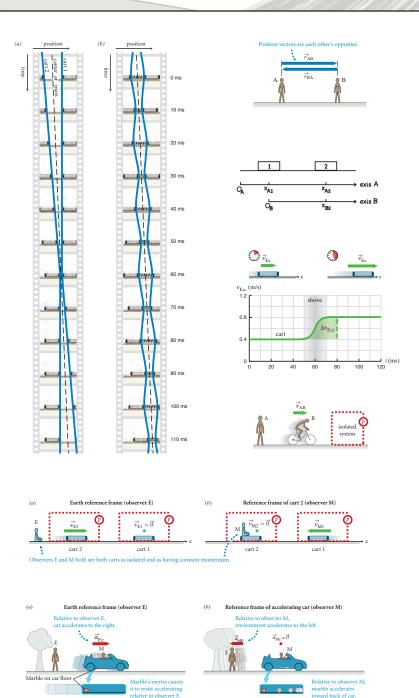
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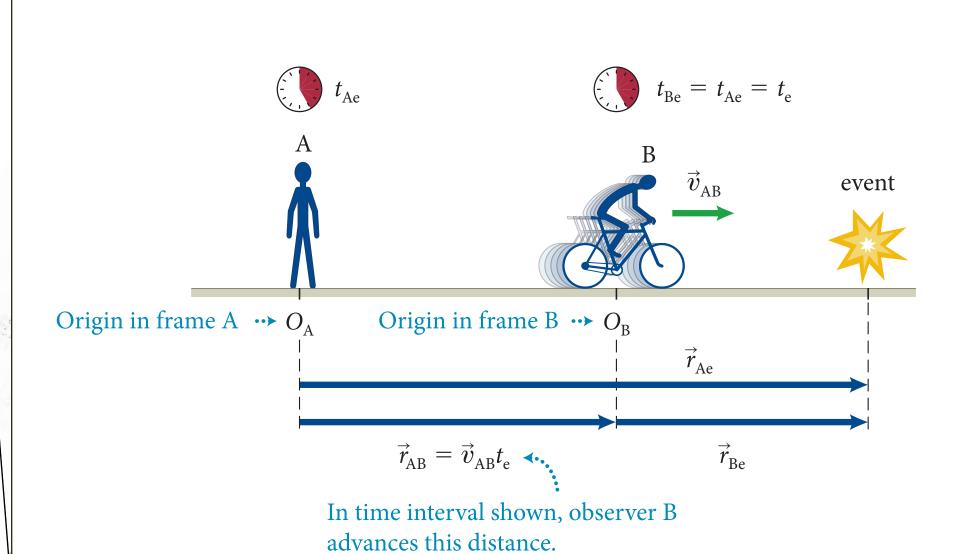
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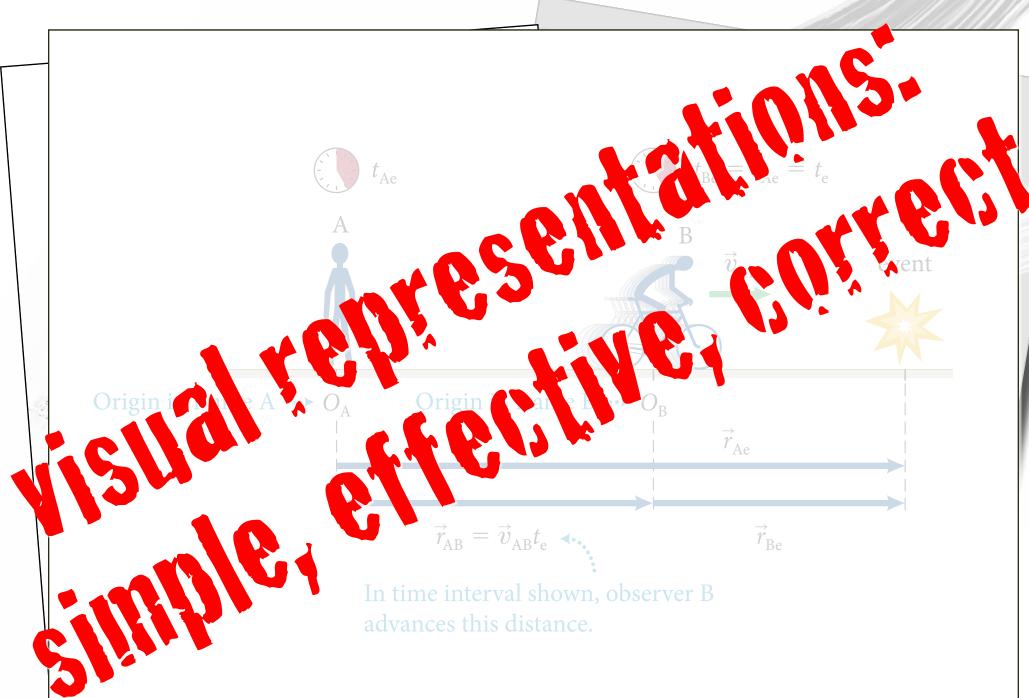
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other. Suppose they observe the same event and describe it relative to their respective reference frames and clocks (Figure 6.13). Let the origins of the two observers' reference frames coincide at t=0 (Figure 6.13a). Observer A sees the event as happening at position \vec{r}_{Ae} at clock reading t_{Ae} (Figure 6.13b).* Observer B sees the event at position \vec{r}_{Be} at clock reading t_{Be} . What is the relationship between these clock readings and positions?

If, as we discussed in Chapter 1, we assume time is absolute—the same every

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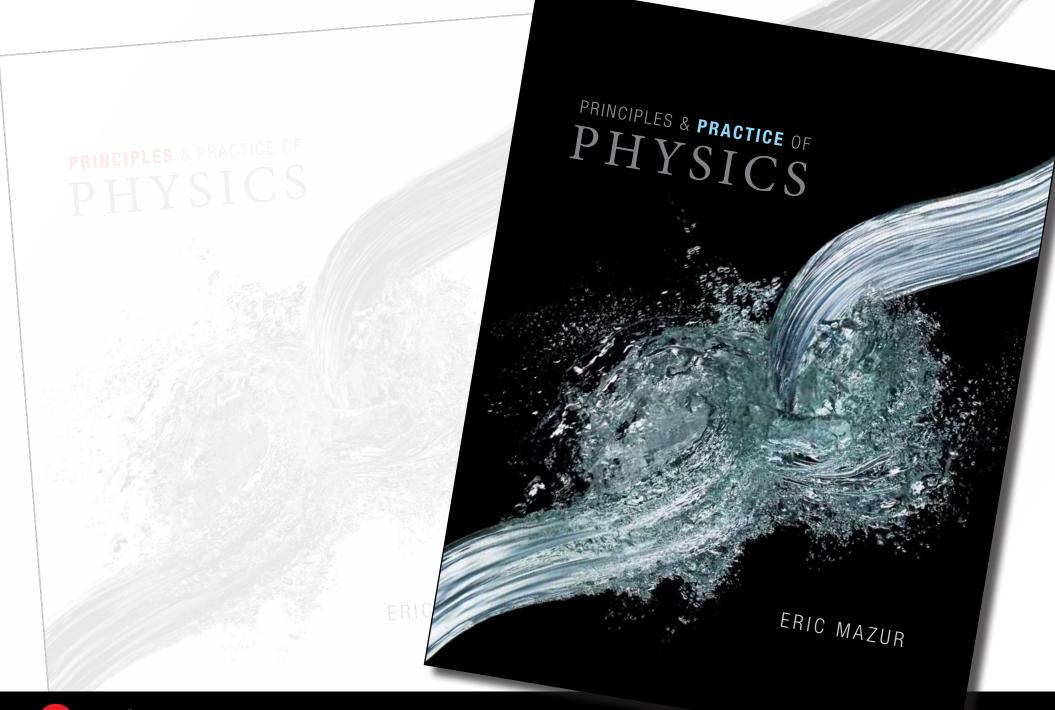
Because the clock readings of the two observers always agree, we can omit the subscripts referring to the reference frames:

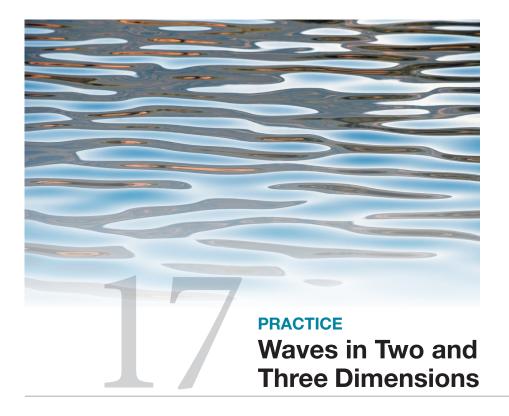
- checkpoints to thinking on \vec{r}_{AB} of observer B in reference frame A at instant t_e is equal to be displacement over the time interval $\Delta t = t_e 0 = t_e$, and so $\vec{r}_{AB} = \vec{v}_{AB} t_e$ because B moves at constant velocity
- 4-step worked examples to data on the same even collected in one reference frame to data on the same even collected in a reference frame that moves at constant velocity relative to the first one (neither of these has to be at rest relative to Earth, but their origins must coincide at t = 0). To this end we rewrite these
- research-based illustrations
- research-based pedagogy



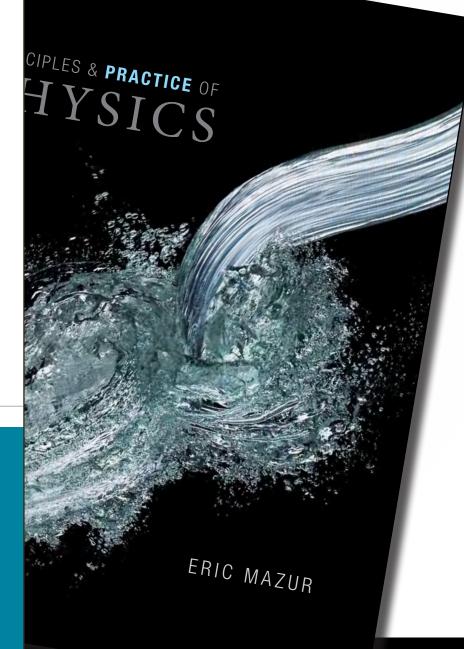
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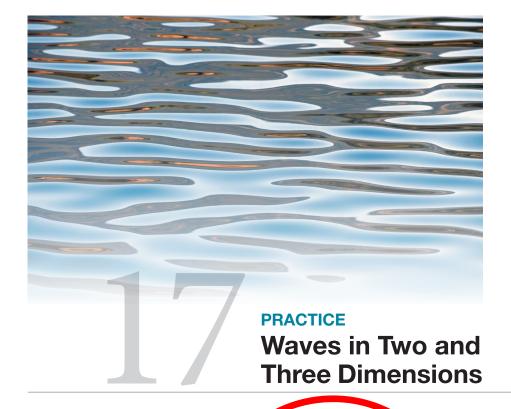
*Remember our subscript form: The capital letter refers to the reference frame; the lowercase e is f





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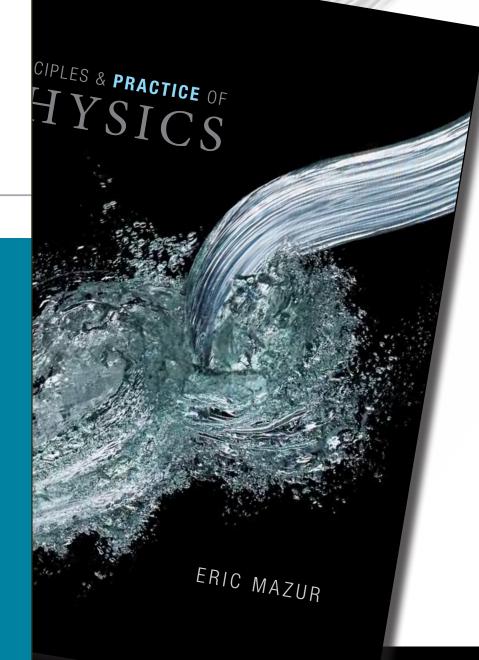
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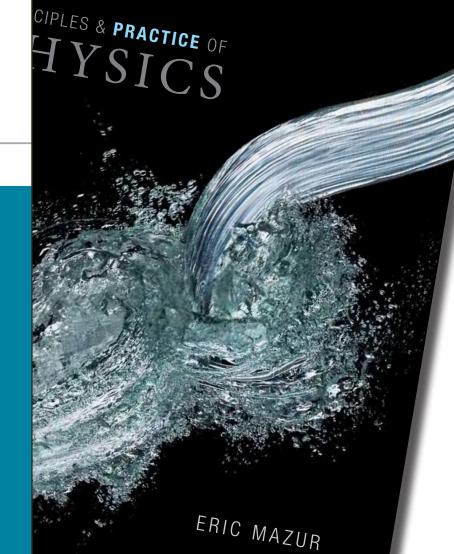
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192 CHAPTER 11 PRACTICE MOTION IN A CIRCLE

Developing a Feel

Make an order-of-magnitude estimate of each of the following quantities. Letters in parentheses refer to hints below. Use them as needed to guide your thinking:

- 1. The speed v of a point on the equator as Earth rotates (D, P)
- 2. The rotational inertia of a bowling ball about an axis tangent to
- 3. Your rotational inertia as you turn over in your sleep (V, C)
- 4. The angular momentum around the axle of a wheel/tire combination on your car as you cruise on the freeway (E, I, O, AA, S)
- 5. The angular momentum of a spinning ice skater with each arm held out to the side and parallel to the ice (G, X, N, U)
- 6. The speed you would need to orbit Earth in a low orbit (F,P)
- 7. The magnitude of the force exerted by the Sun on Earth to hold
- 8. The kinetic energy associated with Earth's rotation (Z, P, D)
- 9. The angular momentum, about a vertical axis through your house, of a large car driving down your street (H, Y, M) 10. The kinetic energy of a spinning yo-yo (K, W, J, Q)

If needed, see Key for answers to these guiding questions.

- A. What is the inertia of a bowling ball? B. How long a time interval is needed for Earth to make one revolu-
- C. What simple geometric shape is an appropriate model for a sleeping person?
- D. What is Earth's rotational speed?
- E. What is the combined inertia of the wheel and tire?
- F. What is the relationship between force and acceleration for this
- G. How can you model the skater's shape during her spin?
- H. What is the inertia of a midsize car?
- I. What is the radius of the tire? J. How many turns are needed to rewind the yo-yo?
- K. What is the yo-yo's rotational inertia?
- L. What is the radius of Earth's orbit?
- M. What is the perpendicular distance from the house to the car's
- N. What is the skater's rotational inertia with arms held out?
- O. How can you model the combined rotational inertia of the wheel and tire?
- P. What is Earth's radius?
- Q. What is the final rotational speed?
- R. What is the radius of a bowling ball?
- S. What is the rotational speed of the tire?
- T. What is the required centripetal acceleration?

- U. What is the skater's initial rotational speed?
- W. When thrown, how long a time interval does the yo-yo take to X. What is needed in addition to the formulas in Principles
- Table 11.3 in order to determine this quantity? Y. What is a typical speed for a car moving on a city street?
- Z. What is Earth's inertia?
- AA. What is a typical freeway cruising speed?

Key (all values approximate)

A. 7 kg; B. 1 y = 3×10^7 s; C. solid cylinder of radius 0.2 m; D. period = 24 h, so $\omega = 7 \times 10^{-5} \text{ s}^{-1}$; E. 10^1 kg ; F. from Eqs. 8.6, 8.17, and 11.16, $\Sigma \vec{F} = m\vec{a}$, so $mg = mv^2/r$; G. a solid cylinder with two thin-rod arms of inertia 4 kg held out perpendicularly; H. 2×10^3 kg; I. 0.3 m; J. 2×10^1 turns; K. 6×10^{-5} kg·m² (with yo-yo modeled as solid cylinder); $L.2 \times 10^{11}$ m; $M.2 \times 10^{1}$ m; N.4 kg·m²; O. between MR^2 (cylindrical shell representing tire) and $MR^2/2$ (solid cylinder representing wheel)—say, $3MR^2/4$; P. 6×10^6 m; Q. about twice the average rotational speed, or $\omega = 5 \times 10^2 \text{ s}^{-1}$; R. 0.1 m; S. no slipping, so $\omega = v/r \approx 10^2 \, \text{s}^{-1}$; T. 8 × 10⁻³ m/s²; U. $\omega \approx 10~{\rm s}^{-1};~{\rm V.7}\times 10^1~{\rm kg};~{\rm W.0.5~s;}~{\rm X.~the~parallel-axis}$ theorem; Y. 3 \times 10 1 mi/h; Z. 6 \times 10 24 kg; AA. 3 \times 10 1 m/s

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Key (all values approximate)

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Waves in Two Three Dimens

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- What is a typical speed for a car moving on a city street? Z. What is Earth's inertia?
- AA. What is a typical freeway cruising speed?

Key (all values approximate)

A. 7 kg; B. 1 $y = 3 \times 10^7$ s; C. solid cylinder of radius 0.2 m; D. period = 24 h, so $\omega = 7 \times 10^{-5} \text{ s}^{-1}$; E. 10^1 kg ; F. from Eqs. 8.6, 8.17, and 11.16, $\Sigma \vec{F} = m\vec{a}$, so $mg = mv^2/r$; G. a solid cylinder with two thin-rod arms of inertia 4 kg held out perpendicularly; H. 2×10^3 kg; I. 0.3 m; J. 2×10^1 turns; K. 6×10^{-5} kg·m² (with yo-yo modeled as solid cylinder); L. 2×10^{11} m; M. 2×10^{1} m; N. $4 \text{ kg} \cdot \text{m}^2$; O. between MR² (cylindrical shell representing tire) and $MR^2/2$ (solid cylinder the average rotational speed, or $\omega = 5 \times 10^2 \text{ s}^{-1}$; R. 0.1 m; S. no slipping, so $\omega = v/r \approx 10^2 \, \text{s}^{-1}$; T. 8 × $10^{-3} \, \text{m/s}^2$; U. $\omega \approx 10~\text{s}^{-1};~V.7 \times 10^1~\text{kg};~W.~0.5~\text{s};~X.$ the parallel-axis theorem; Y. 3 \times 10 1 mi/h; Z. 6 \times 10 24 kg; AA. 3 \times 10 1 m/s

Waves in Two and Three Dimensions

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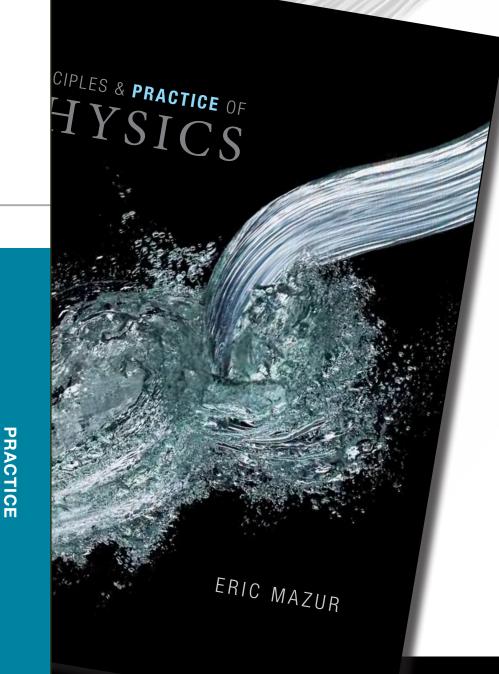
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Waves in Two a **Three Dimension**

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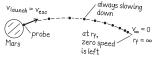
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238 CHAPTER 13 PRACTICE GRAVITY

Worked Problem 13.3 Escape at last

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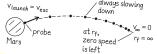
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238 CHAPTER 13 PRACTICE GRAVITY

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Worked Problem 13.3 Escape at last

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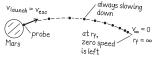
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Waves in Two a **Three Dimension**

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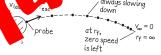
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238 CHAPTER 13 PRACTICE GRAVITY

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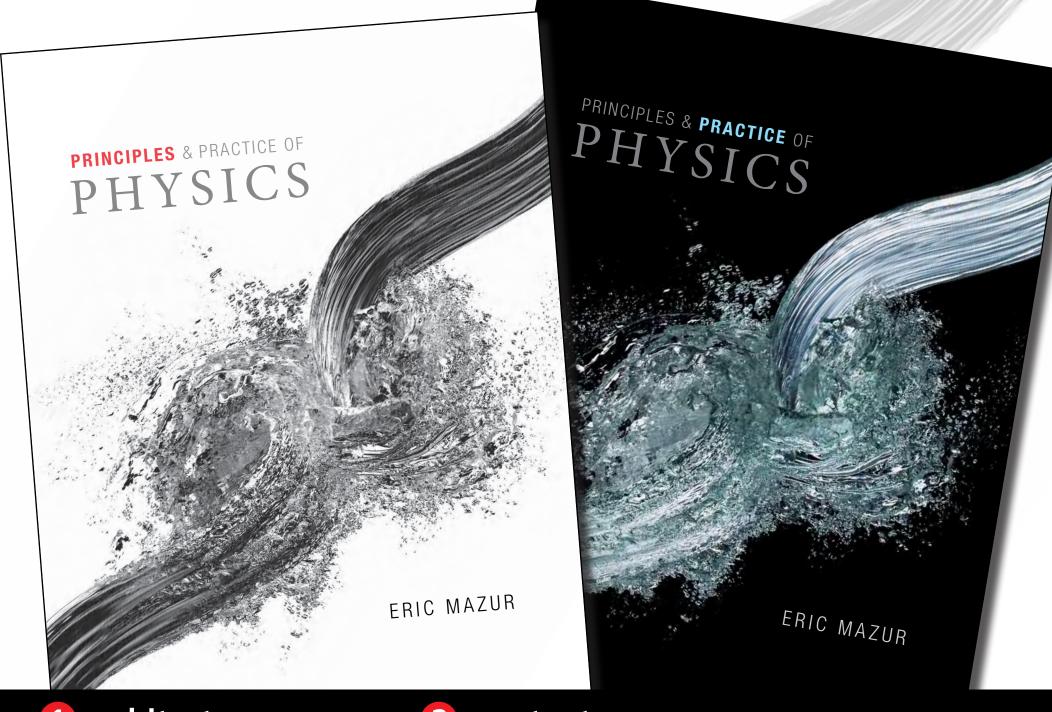
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not just end-of-chapter material

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many innovative features

teaches authentic problem solving



1 architecture

2 content

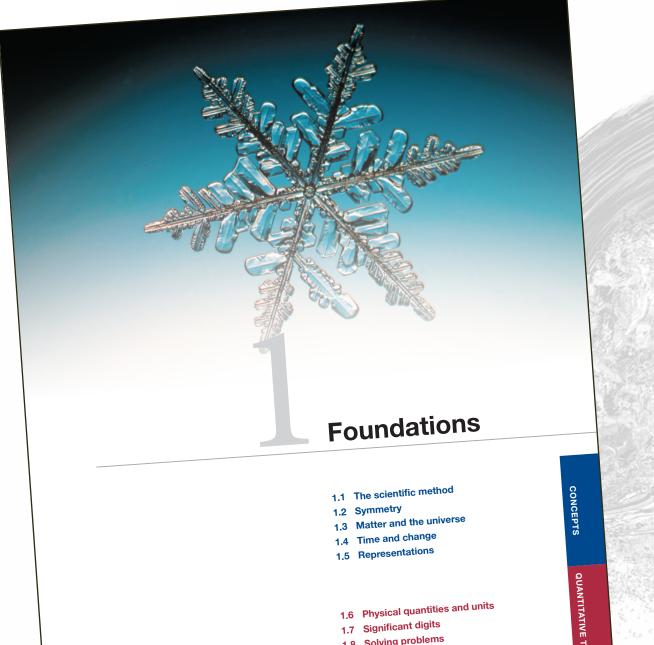
PRINCIPLES & PRACTICE OF PRINCIPLES & PRACTICE OF

PHYSICS & PRACTICE OF

conservation principles before force laws?

ERIC MAZUR

ERIC MAZIII

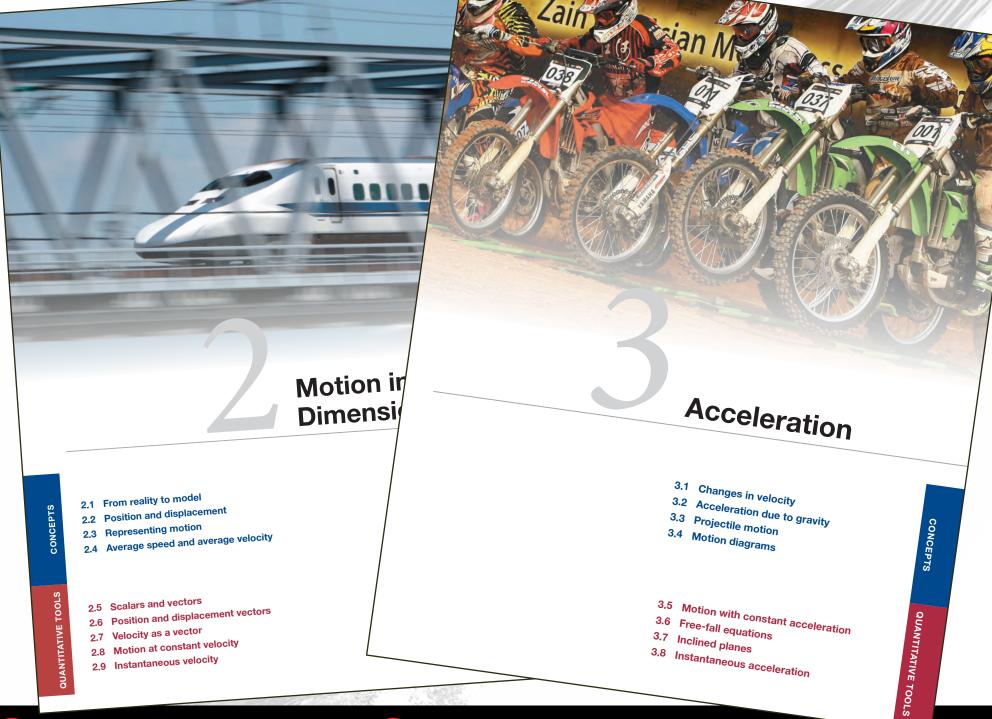


- 1.8 Solving problems
- 1.9 Developing a feel



- 1.1 The scientific method
- 1.2 Symmetry
- 1.3 Matter and the universe
- 1.4 Time and change
- 1.5 Representations

- 1.6 Physical quantities and units
- 1.7 Significant digits
- 1.8 Solving problems
- 1.9 Developing a feel



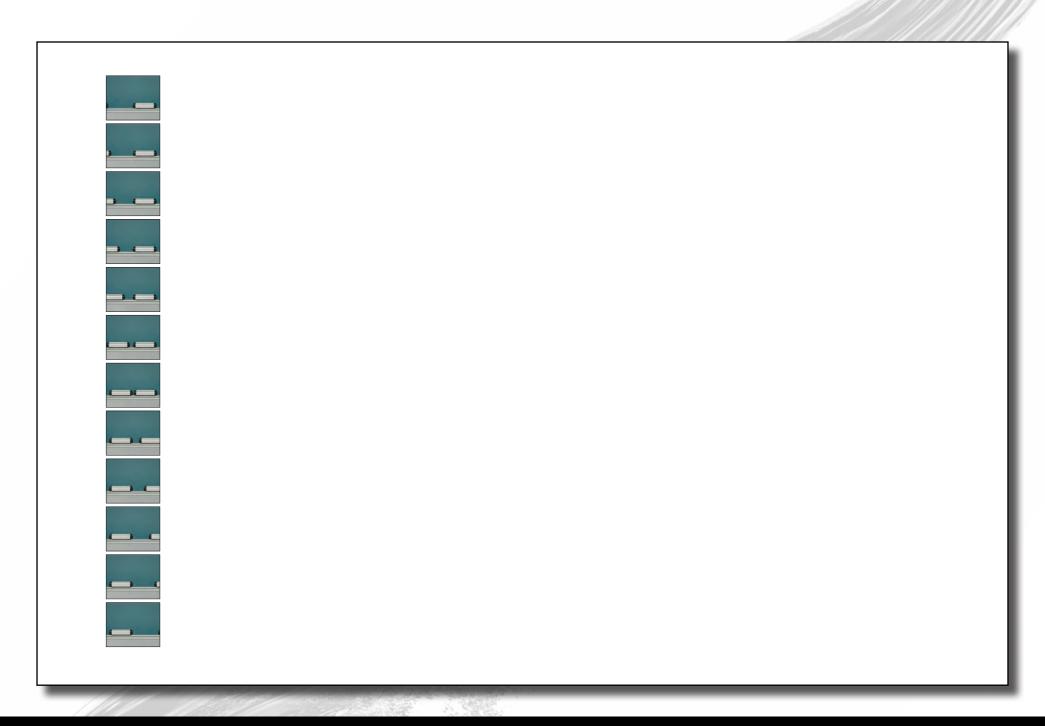


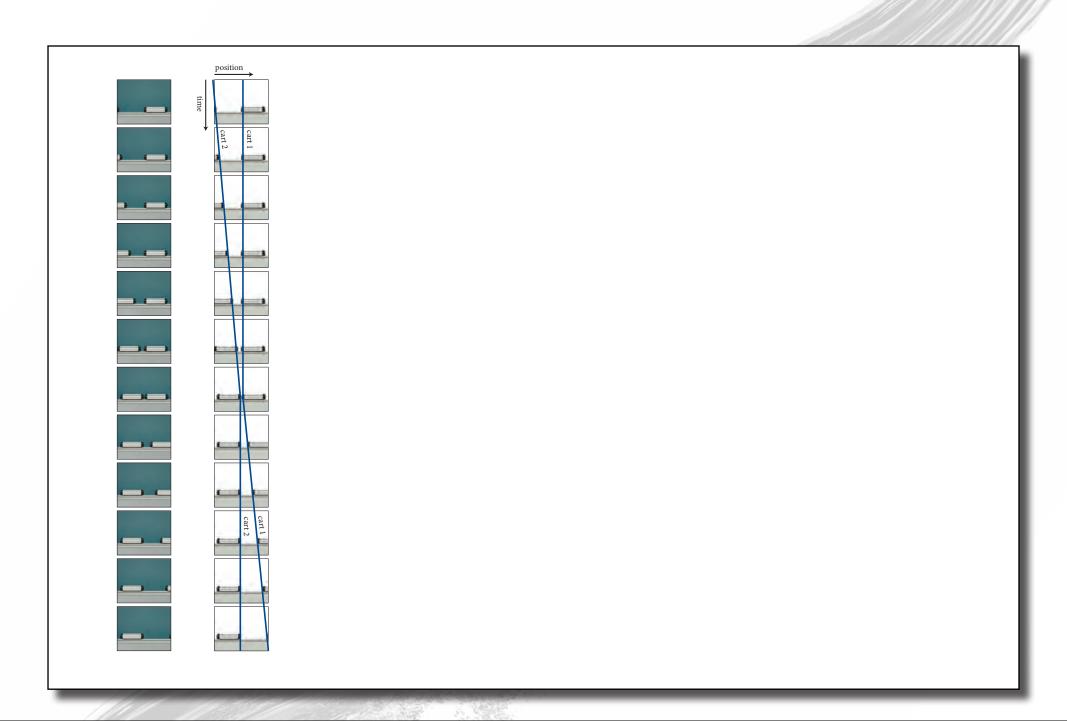
- 4.6 Momentum
- 4.7 Isolated systems
- 4.8 Conservation of momentum

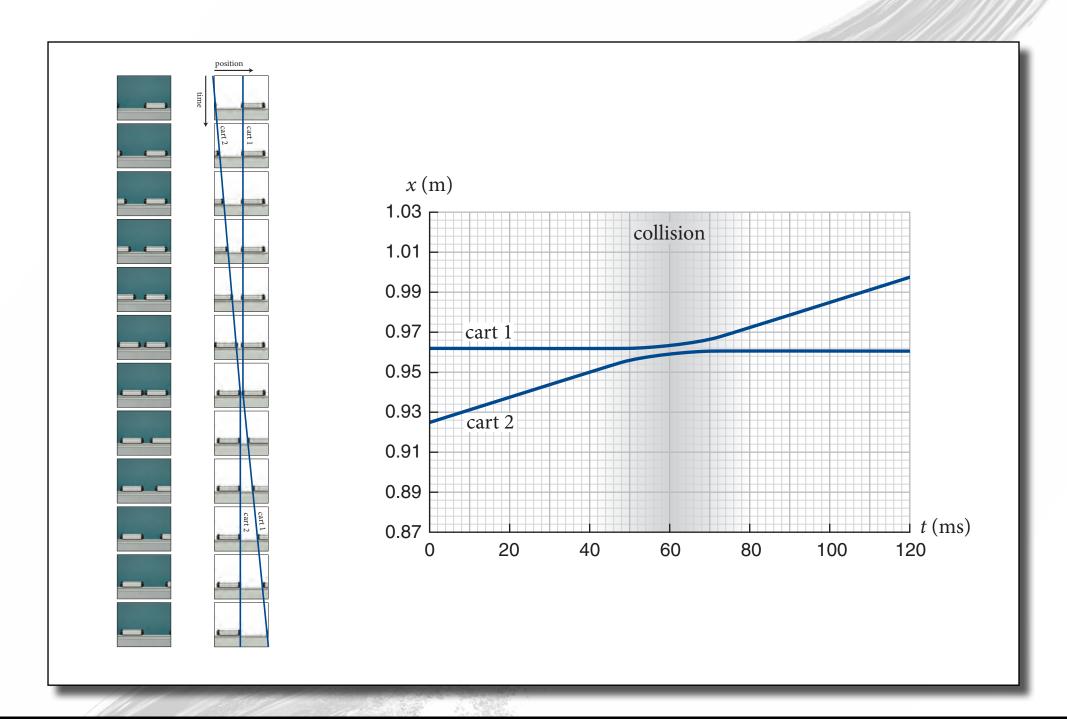
NTITATIVE TOOLS

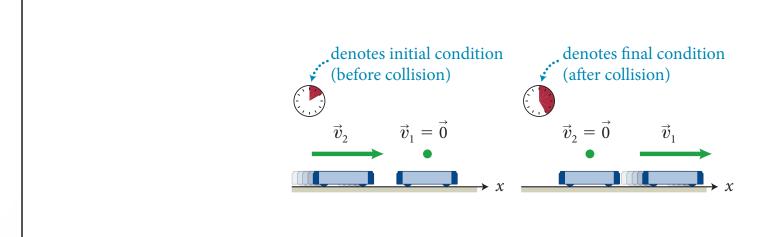
- 4.1 Friction
- 4.2 Inertia
- 4.3 What determines inertia?
- 4.4 Systems

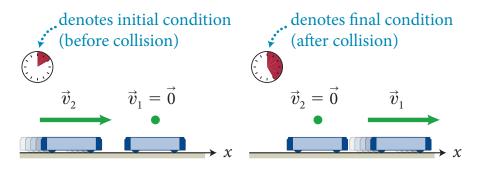
- 4.5 Inertial standard
- 4.6 Momentum
- 4.7 Isolated systems
- 4.8 Conservation of momentum

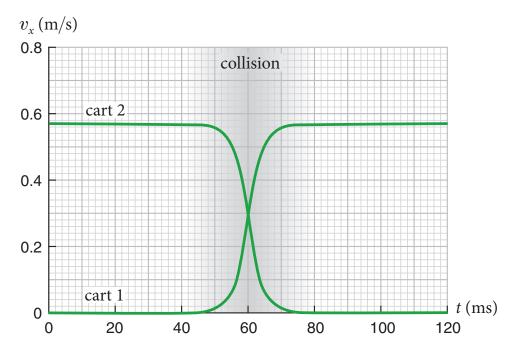


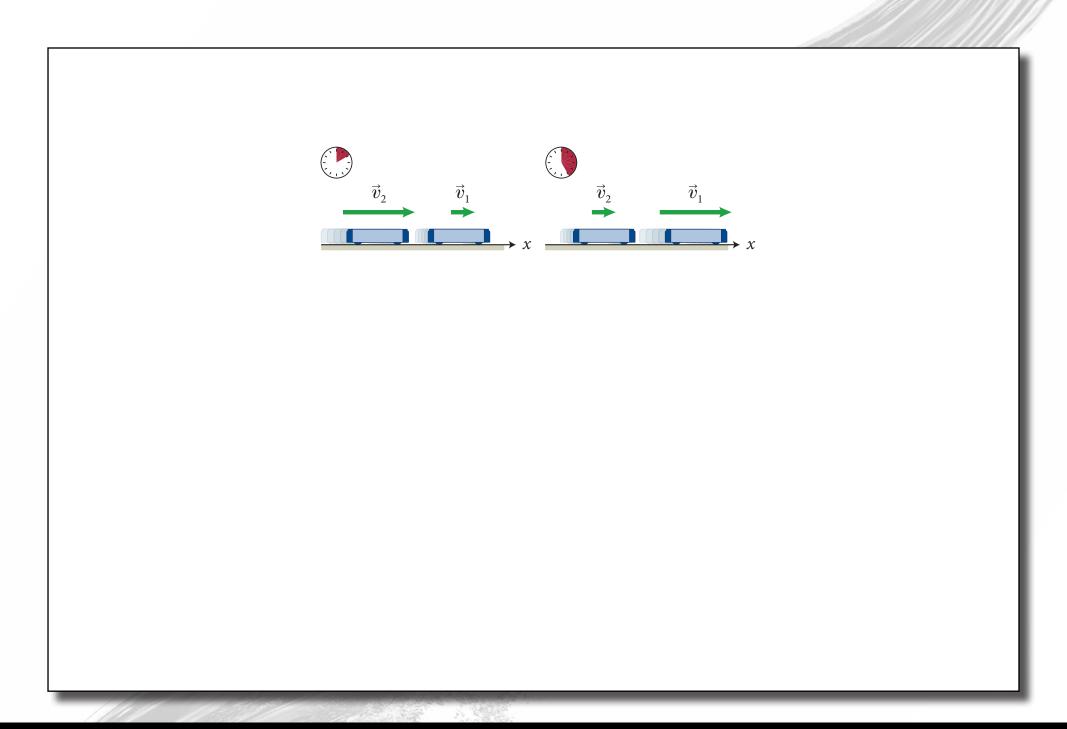


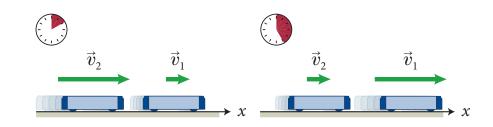


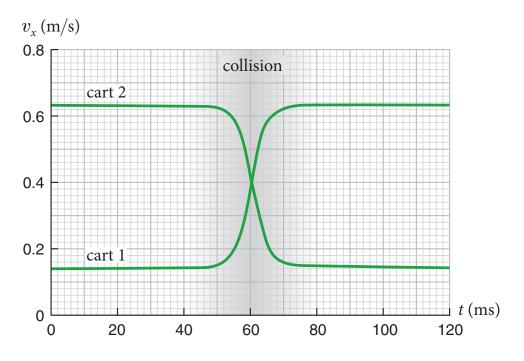


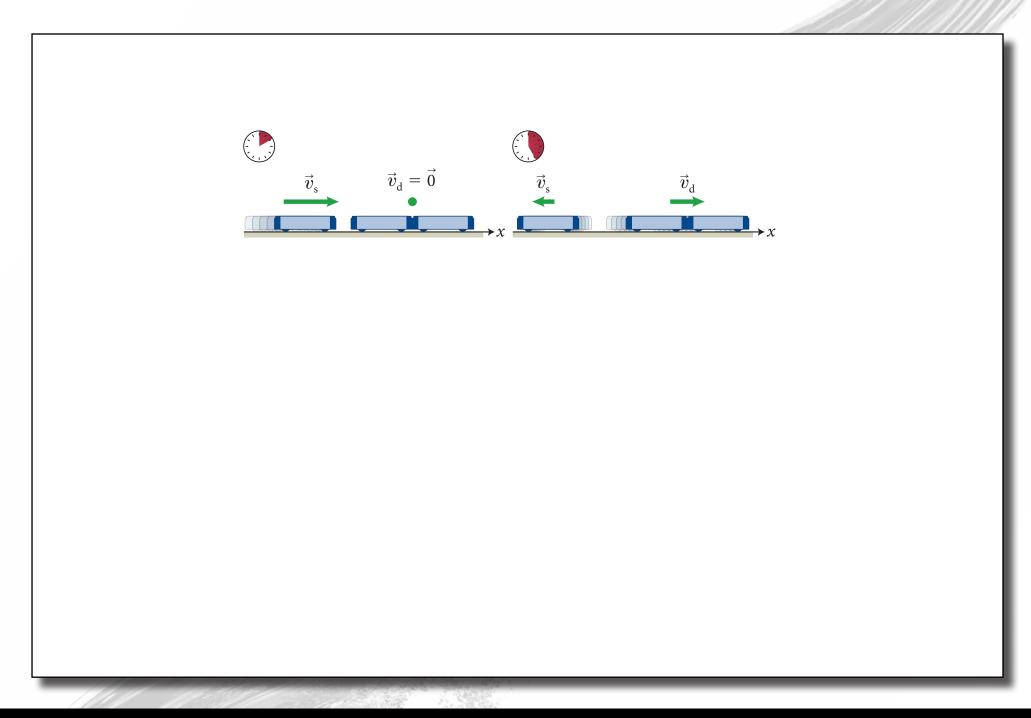


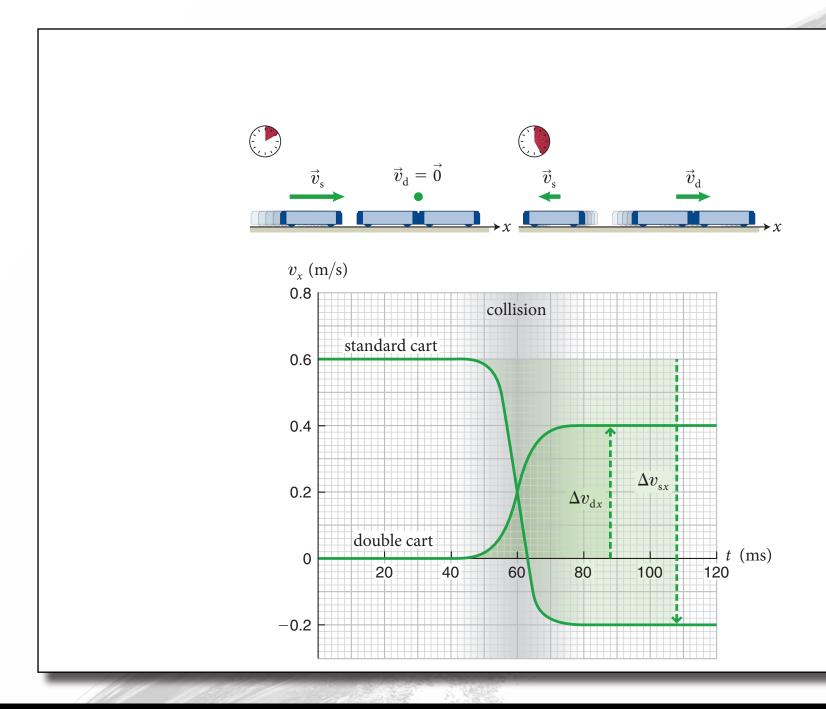


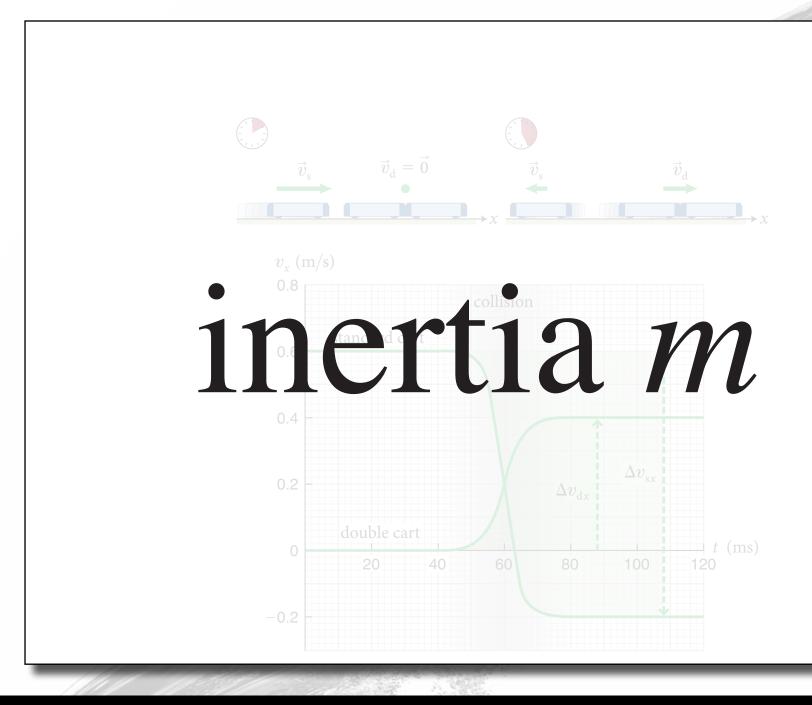


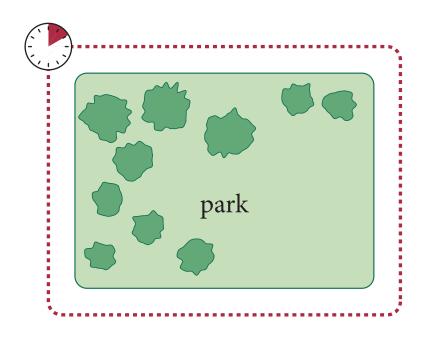


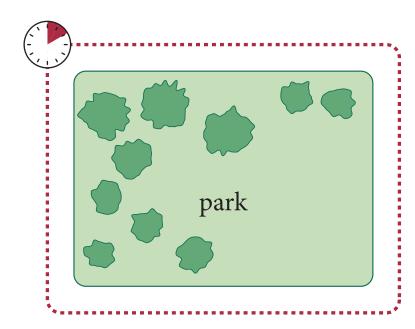


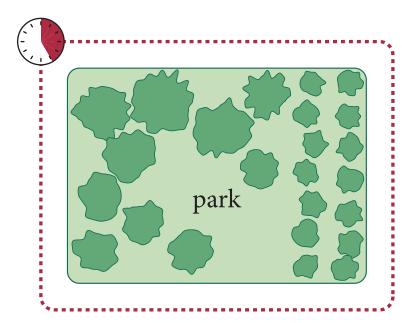
















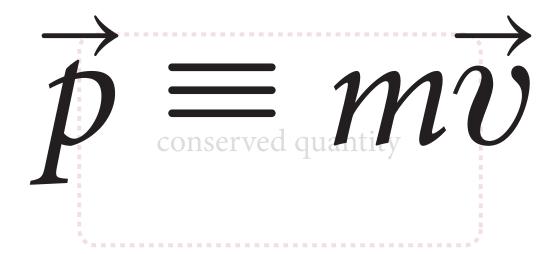


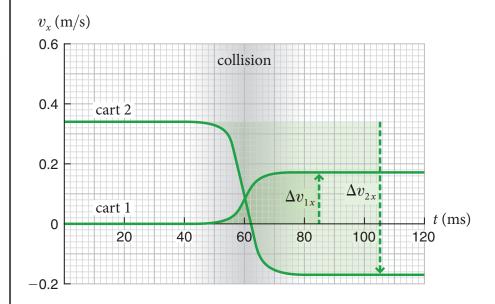


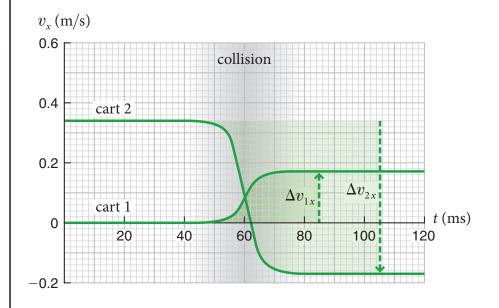
conserved quantity

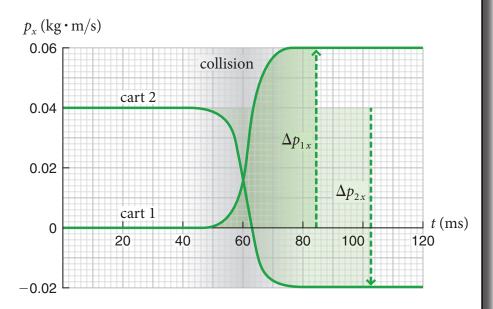
conserved quantity in isolated system

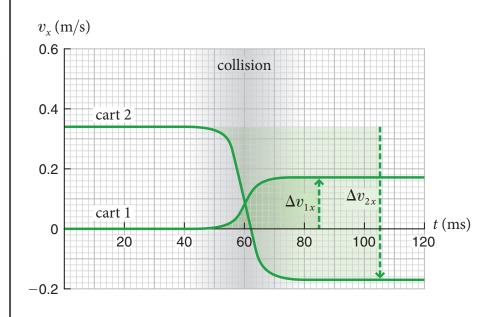
can't change (constant)

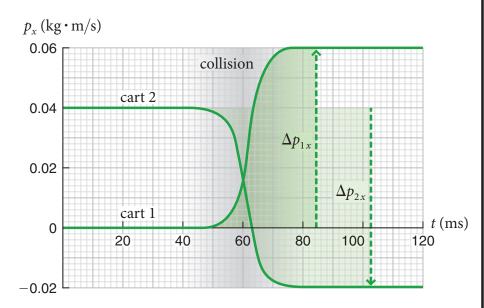




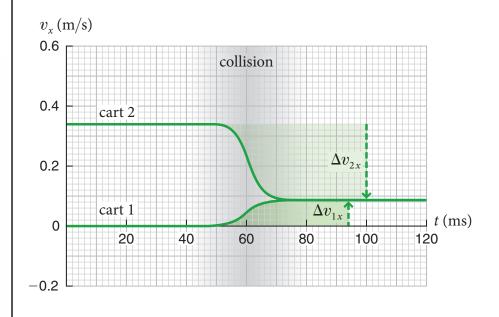


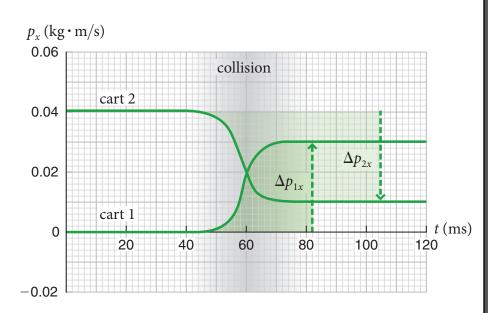




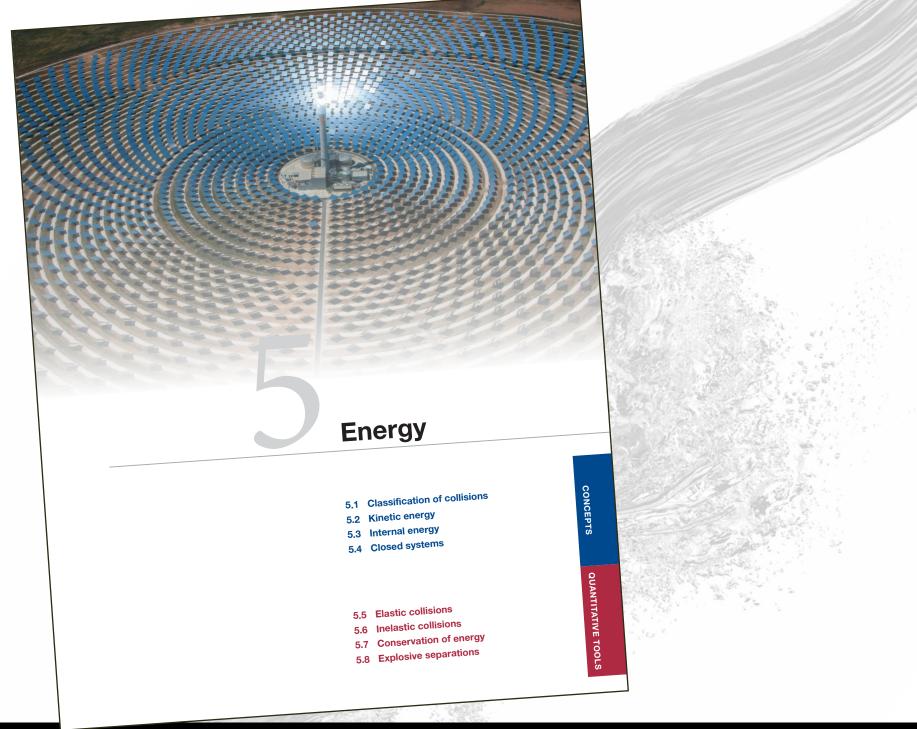


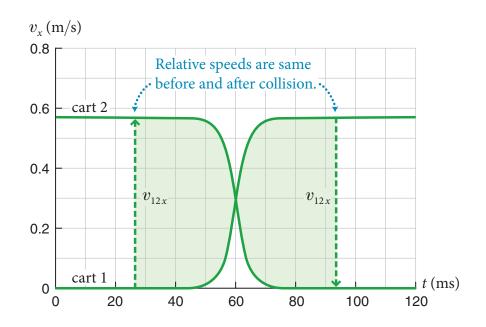
$$\Delta \vec{p} \equiv \Delta \vec{p}_1 + \Delta \vec{p}_2 = \vec{0}.$$

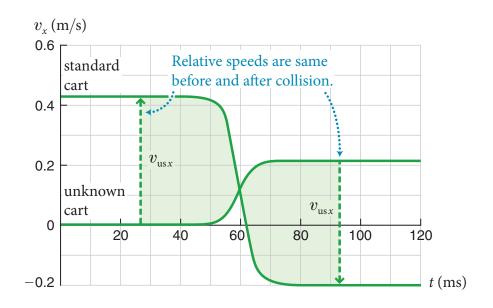




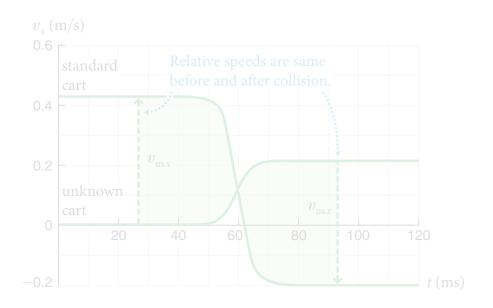
$$\Delta \vec{p} = \Delta \vec{p}_1 + \Delta \vec{p}_2 = \vec{0}.$$



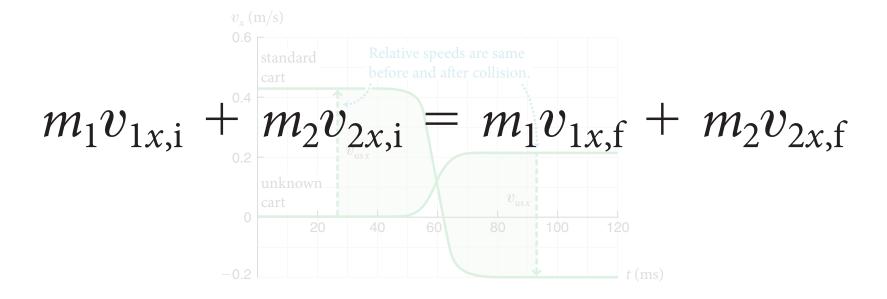




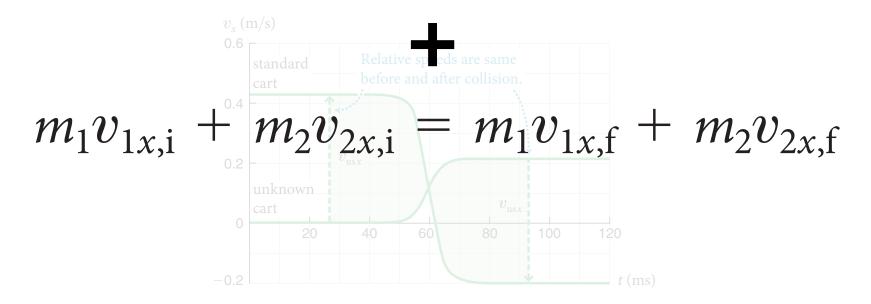
$$v_{12i} = v_{12f}$$



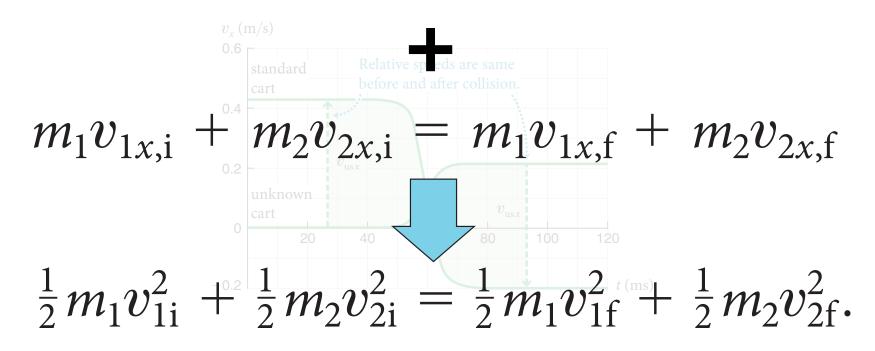
$$v_{12i} = v_{12f}$$



$$v_{12i} = v_{12f}$$



$$v_{12i} = v_{12f}$$









elastic: reversible

inelastic: irreversible

type	relative speed	state unchanged	
elastic	unchanged		
inelastic	changed	changed	

type	relative speed	state unchanged	
elastic	unchanged		
inelastic	changed	changed	
	ΔK		

type	relative speed	state unchanged	
elastic	unchanged		
inelastic	changed	changed	
	ΔK	ΔE_{int}	

conservation of energy

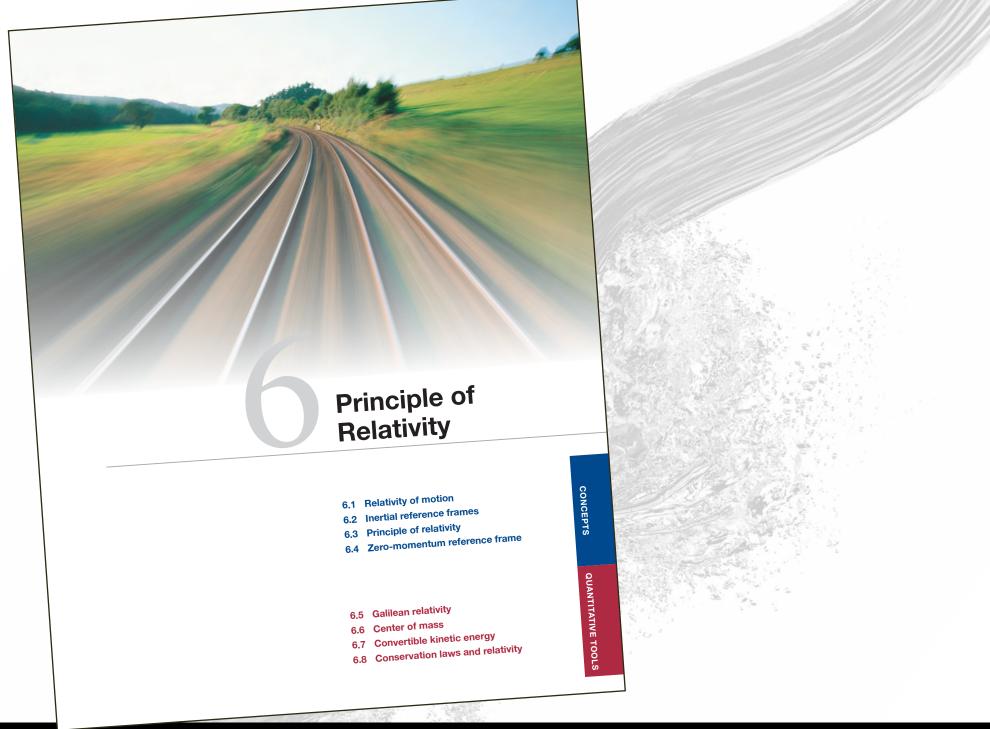
$$E = K + E_{\text{int}}$$

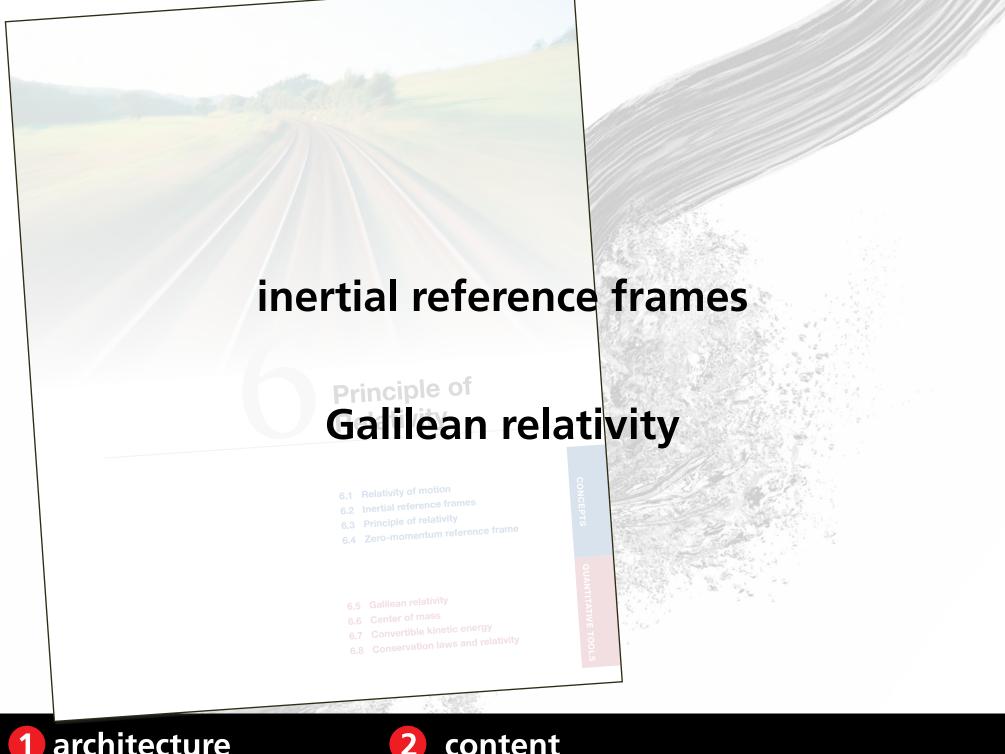
conservation of energy

$$E = K + E_{\text{int}}$$

closed system:

$$\Delta E = 0$$





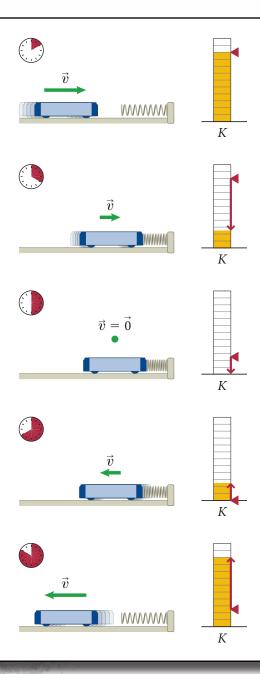
- 7.8 Nondissipative interactions
- 7.9 Potential energy near Earth's surface
- 7.10 Dissipative interactions

- 7.1 The effects of interactions
- 7.2 Potential energy
- **7.3 Energy dissipation**
- Source energy
- **7.5** Interaction range
- 7.6 Fundamental interactions

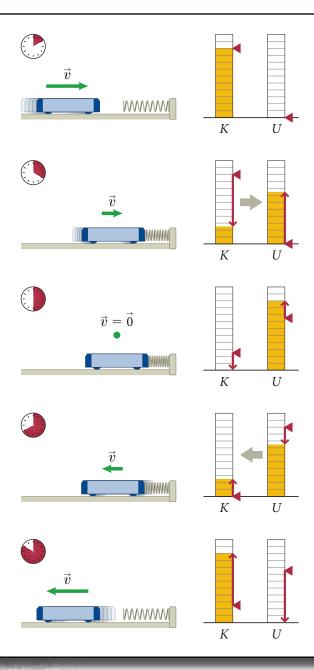
- 7.5 Interaction range
- 7.6 Fundamental interactions
- 7.7 Interactions and accelera
- 7.8 Nondissipative interaction
- 7.9 Potential energy near Ea
- 7.10 Dissipative interactions

- 7.7 Interactions and accelerations
- 7.8 **Nondissipative interactions**
- 7.9 Potential energy near Earth's surface
- 7.10 Dissipative interactions

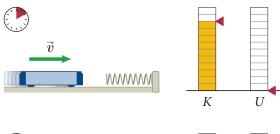
potential energy

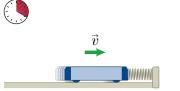


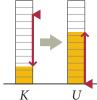
potential energy

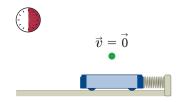


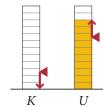
potential energy



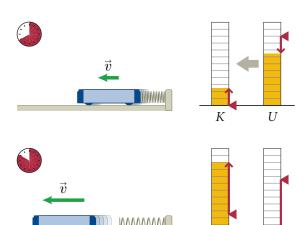






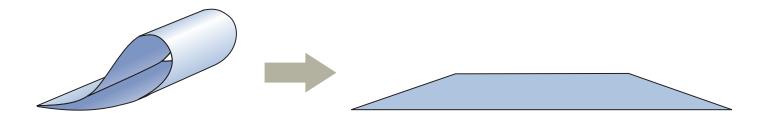






reversible and irreversible state changes

(a) Coherent deformation: reversible

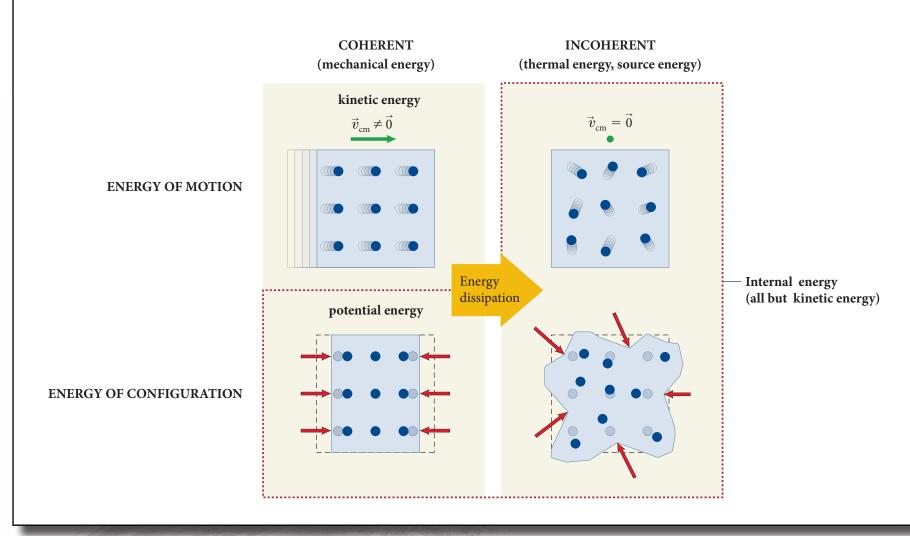


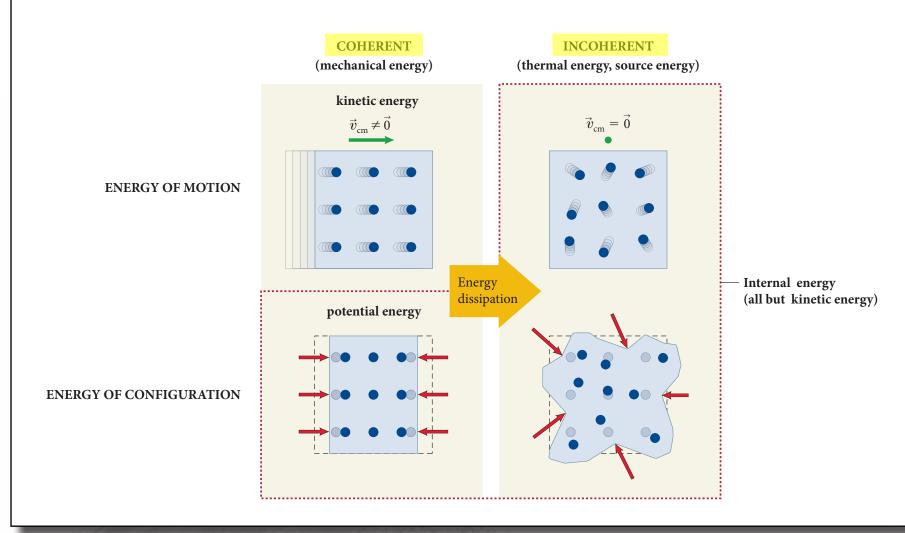
(b) Incoherent deformation: irreversible

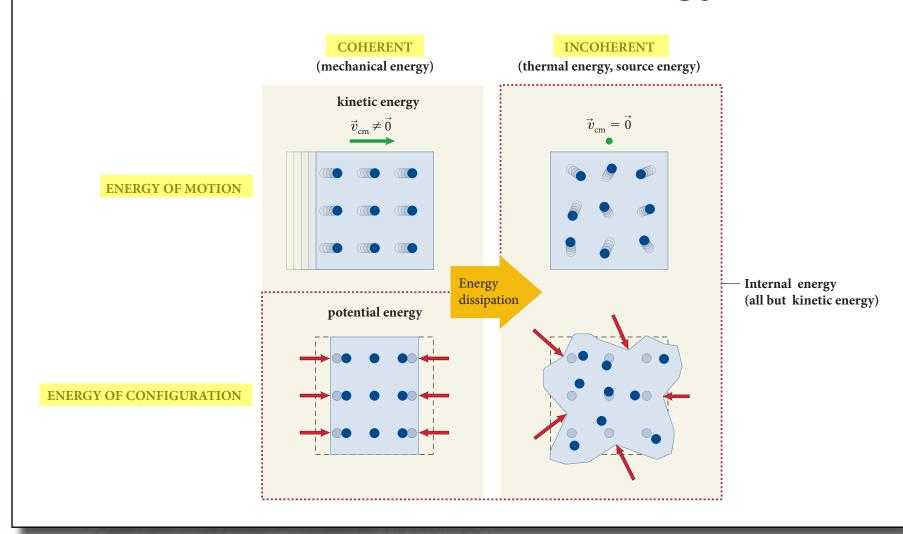


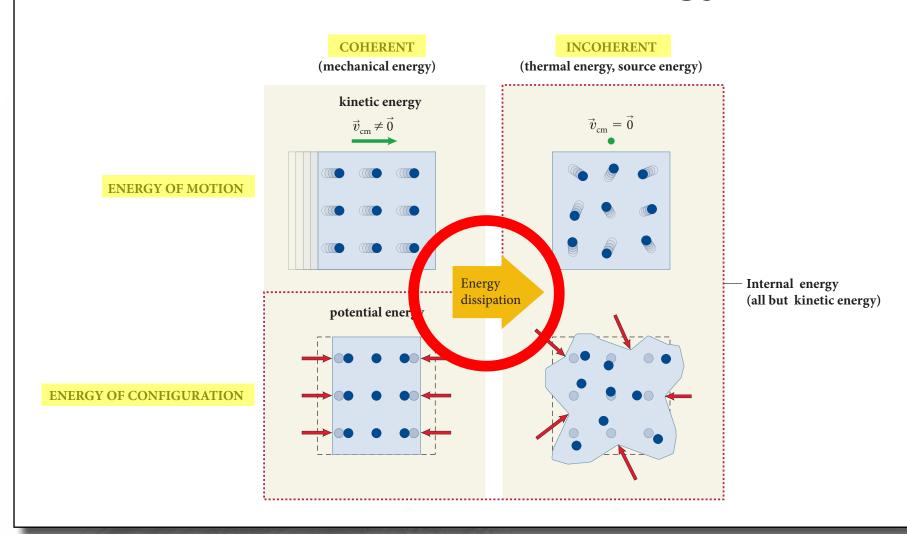




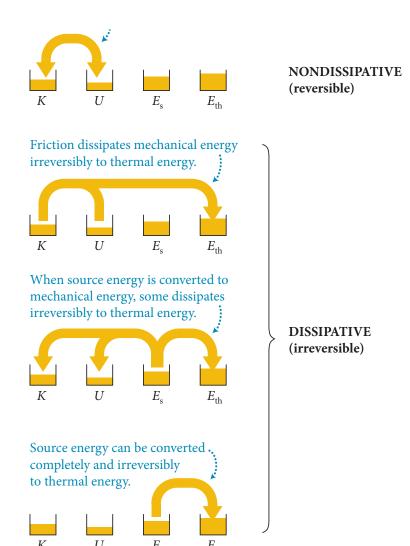




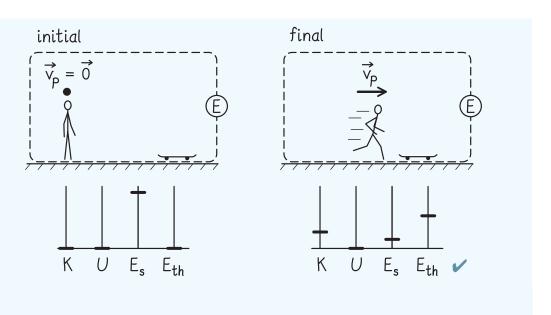




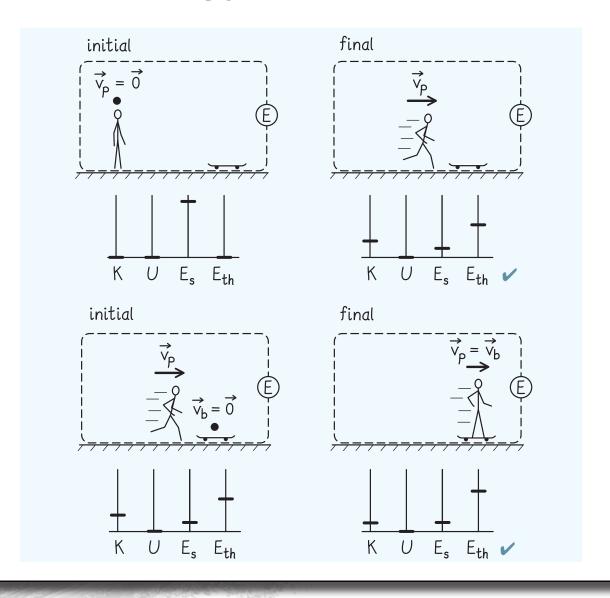
energy conversions



energy conversions



energy conversions





- 8.3 Identifying forces
- 8.4 Translational equilibrium
- 8.5 Free-body diagrams
- 8.6 Springs and tension
- 8.7 Equation of motion
- 8.8 Force of gravity
- 8.9 Hooke's law
- 8.10 Impulse
- 8.11 Systems of two interacting objects
- 8.12 Systems of many interacting objects



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2			d	
		2	1	K
	8.1	Momentu	m and for	ce orces

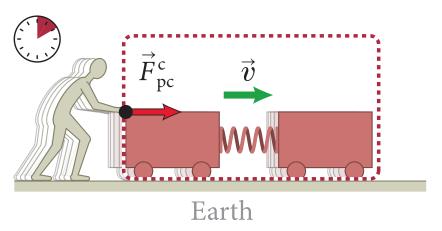
- 8.2 The reciprocity of force
- 8.3 Identifying forces
- 8.4 Translational equilibrium
- 8.5 Free-body diagrams
- 8.6 Springs and tension
- 8.7 Equation of motion
- 8.8 Force of gravity
- 8.9 Hooke's law
- 8.10 Impulse
- 8.11 Systems of two interac
- 8.12 Systems of many intera

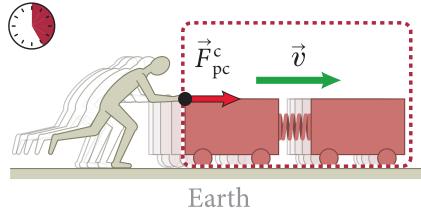
- **Momentum and force**
- 8.2 The reciprocity of forces
- **Identifying forces**
- 8.4 Translational equilibrium
- Free-body diagrams
- Springs and tension 8.6
- **Equation of motion**
- Force of gravity 8.8
- Hooke's law 8.9
- 8.10 **Impulse**
- Systems of two interacting objects 8.11
- **Systems of many interacting objects**

- 9.4 Choice of system
- 9.5 Work done on a single particle
- 9.6 Work done on a many-particle system

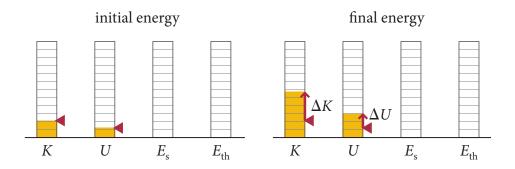
Work

- 9.7 Variable and distributed forces
- 9.8 Power

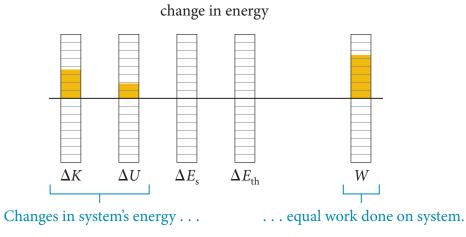


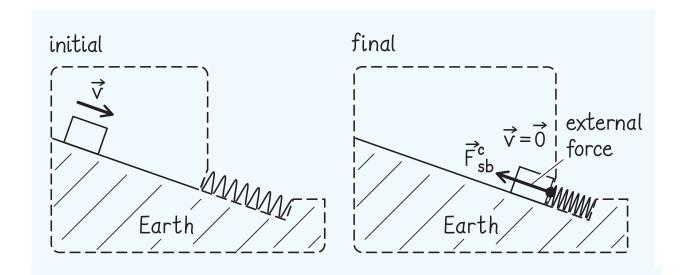


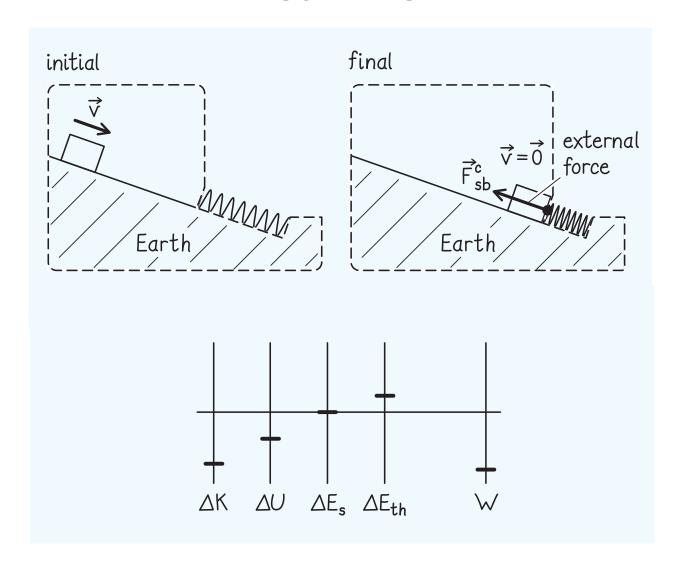
We can represent the changes in energy by initial and final bar diagrams . . .



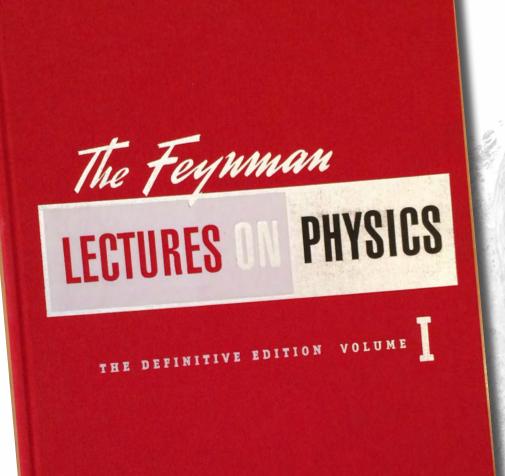
(c) . . . or by a single **energy diagram**.



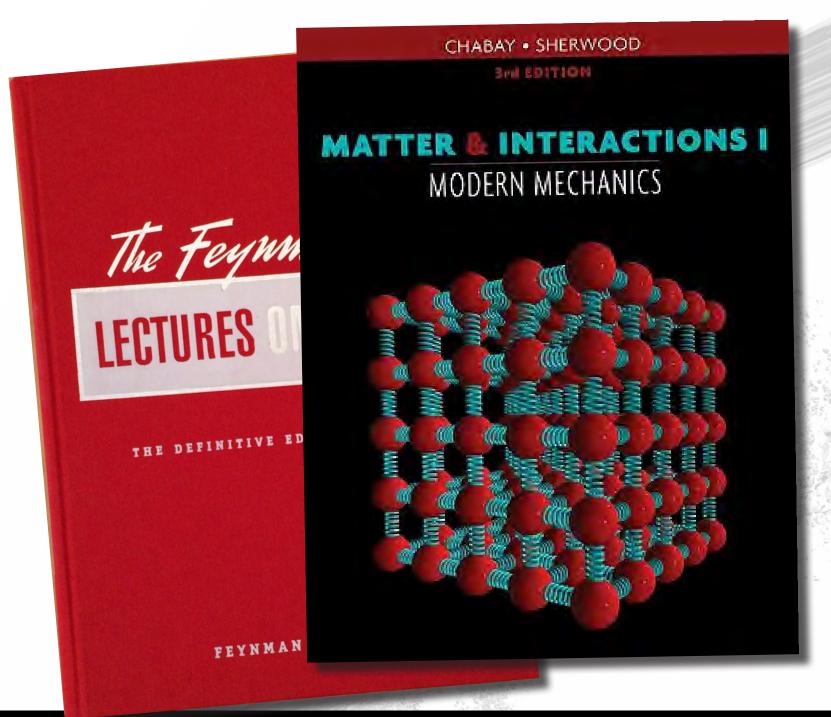




how much work is it to switch?

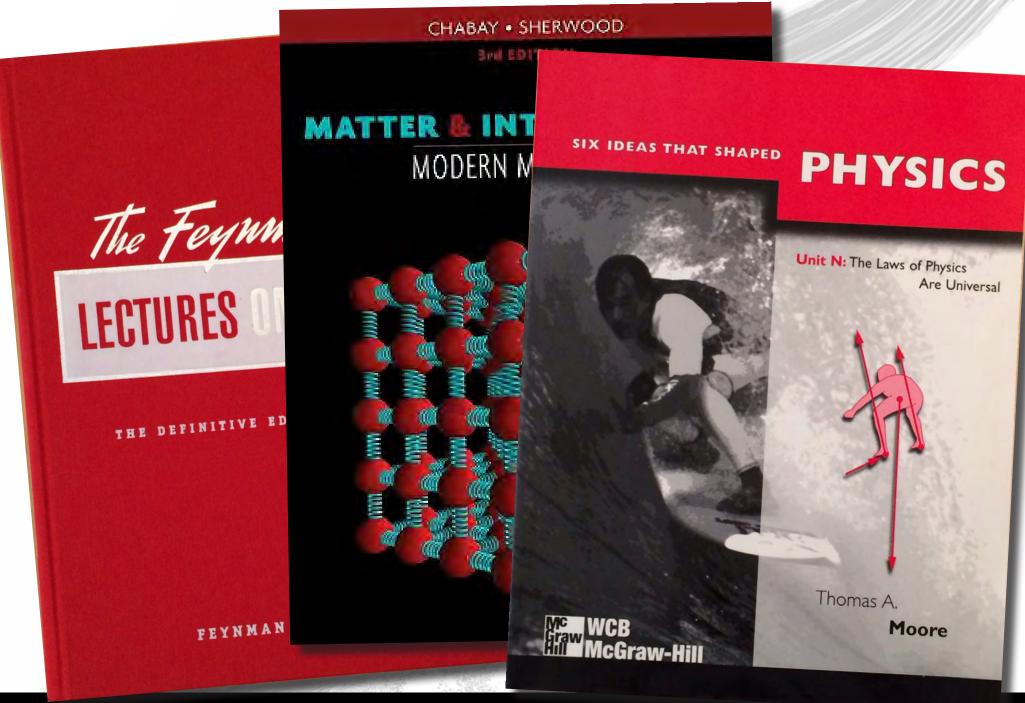


FEYNMAN · LEIGHTON · SANDS



1 architecture

2 content



1 architecture

2 content

Principles and Practice

- 1. Physics and measurement
- 2. Motion in one dimension
- 3. Vectors
- 4. Motion in two dimensions
- 5. The laws of motion
- 6. Circular motion
- 7. Work and kinetic energy
- 8. Potential energy and CoE
- 9. Momentum and collisions
- 10. Rotation about a fixed axis
- 11. Rolling motion and angular momentum
- 12. Static equilibrium and elasticity
- 13. Oscillatory motion
- 14. The law of gravity
- 15. Fluid mechanics
- 16. Wave motion
- 17. Sound waves
- 18. Superposition and standing waves

- 1. Foundations
- 2. Motion in one dimension
- 3. Acceleration
- 4. Momentum
- 5. Energy
- 6. Principle of relativity
- 7. Interactions
- 8. Force
- 9. Work
- 10. Motion in a plane
- 11. Motion in a circle
- 12. Torque
- 13. Gravity
- 14. Special Relativity
- 15. Periodic Motion
- 16. Waves in one dimension
- 17. Waves in 2 and 3 dimensions
- 18. Fluids

Principles and Practice

1. Physics and measurement	1. Foundations
2. Motion in one dimension	2. Motion in one dimension
3. Vectors	3. Acceleration
4. Motion in two dimensions	4. Momentum
5. The laws of motion	5. Energy 1D
6. Circular motion	6. Principle of relativity
7. Work and kinetic energy	7. Interactions
8. Potential energy and CoE	8. Force
9. Momentum and collisions	9. Work
10. Rotation about a fixed axis	10. Motion in a plane
11. Rolling motion and angular momentum	11. Motion in a circle
12. Static equilibrium and elasticity	12. Torque
13. Oscillatory motion	13. Gravity
14. The law of gravity	14. Special Relativity
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17. Sound waves	17. Waves in 2 and 3 dimensions

18. Superposition and standing waves

18. Fluids

Principles and Practice

1D

3D

1. Physics and measurement

2. Motion in one dimension

3. Vectors

4. Motion in two dimensions

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Principles and Practice

1D

3D

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15. Periodic Motion

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17. Waves in 2 and 3 dimensions

18. Fluids

1 architecture



Principles and Practice

1. Foundations 1. Physics and measurement 2. Motion in one dimension 2. Motion in one dimension 3. Acceleration 3. Vectors 4. Motion in two dimensions 4. Momentum 5. The laws of motion 5. Energy 1D 6. Circular motion 6. Principle of relativity 7. Work and kinetic energy 7. Interactions 8. Potential energy and CoE 8. Force 9. Momentum and collisions 9. Work 10. Rotation about a fixed axis 10. Motion in a plane 11. Rolling motion and angular momentum 11. Motion in a circle **3D** 12. Static equilibrium and elasticity 12. Torque 13. Oscillatory motion 13. Gravity 14. The law of gravity 14. Special Relativity 15. Fluid mechanics 15. Periodic Motion 16. Waves in one dimension 16. Wave motion 17. Sound waves 17. Waves in 2 and 3 dimensions 18. Superposition and standing waves 18. Fluids

Principles and Practice

1. Foundations	
2. Motion in one dimension	
3. Acceleration	
4. Momentum	
5. Energy conser	vation
6. Principle of relativity	vacion
7. Interactions	
8. Force	amicc
9. Work	namics
10. Motion in a plane	
11. Motion in a circle	
12. Torque	
13. Gravity	
14. Special Relativity	
15. Periodic Motion	
16. Waves in one dimension	
17. Waves in 2 and 3 dimensions	
18. Fluids	
	 2. Motion in one dimension 3. Acceleration 4. Momentum 5. Energy

Principles and Practice

1. Physics and measurement	1. Foundations		
2. Motion in one dimension	2. Motion in one dimension		
3. Vectors	3. Acceleration		
4. Motion in two dimensions	4. Momentum		
5. The laws of motion	5. Energy		
6. Circular motion	6. Principle of relativity		
7. Work and kinetic energy	7. Interactions		
8. Potential energy and CoE	8. Force		
9. Momentum and collisions	9. Work		
10. Rotation about a fixed axis	10. Motion in a plane		
11. Rolling motion and angular momentum	11. Motion in a circle		
12. Static equilibrium and elasticity	12. Torque rotation		
13. Oscillatory motion	13. Gravity		
14. The law of gravity	14. Special Relativity		
15. Fluid mechanics	15. Periodic Motion		
16. Wave motion	16. Waves in one dimension		
17. Sound waves	17. Waves in 2 and 3 dimensions		
18. Superposition and standing waves	18. Fluids		

Principles and Practice

1.	Physics	and	measure	ment
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- 2. Motion in one dimension
- 3. Vectors
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- 16. Waves in one dimension
- 17. Waves in 2 and 3 dimensions
- 18. Fluids

periodic

mostly minor rearrangements!

easily custom tailored

TO THE INSTRUCTOR

VII

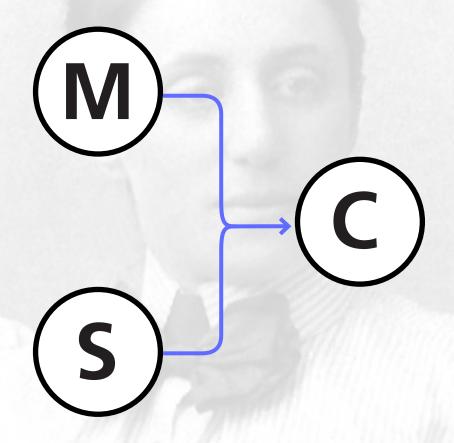
Table 1 Scheduling matrix

Торіс	Chapters	Can be inserted after chapter	Chapters that can be omitted without affecting continuity
Mechanics	1-14		6, 13–14
Waves	15–17	12	16–17
Fluids	18	9	
Thermal Physics	19–21	10	21
Electricity & Magnetism	22-30	12 (but 17 is needed for 29–30)	29–30
Circuits	31-32	26 (but 30 is needed for 32)	32
Optics	33-34	17	34

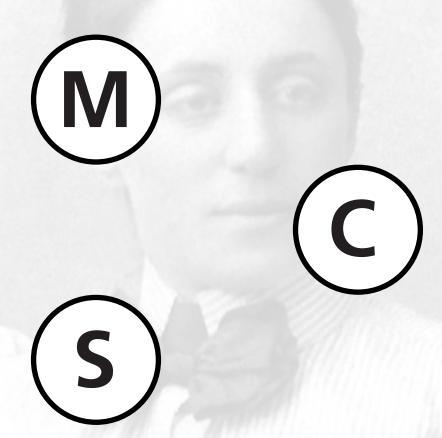
Emmy Noether



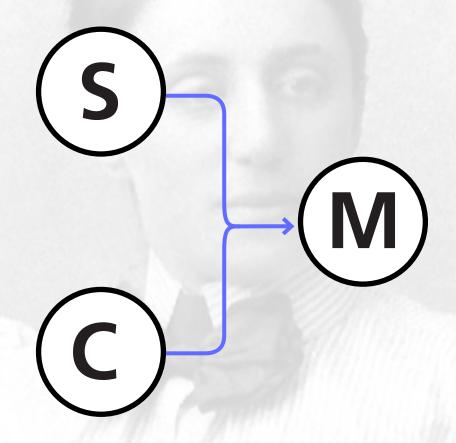
Emmy Noether



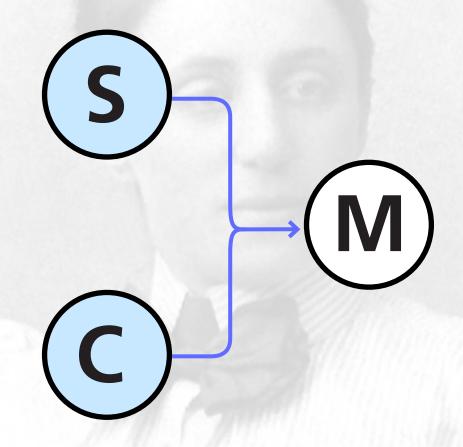
Emmy Noether



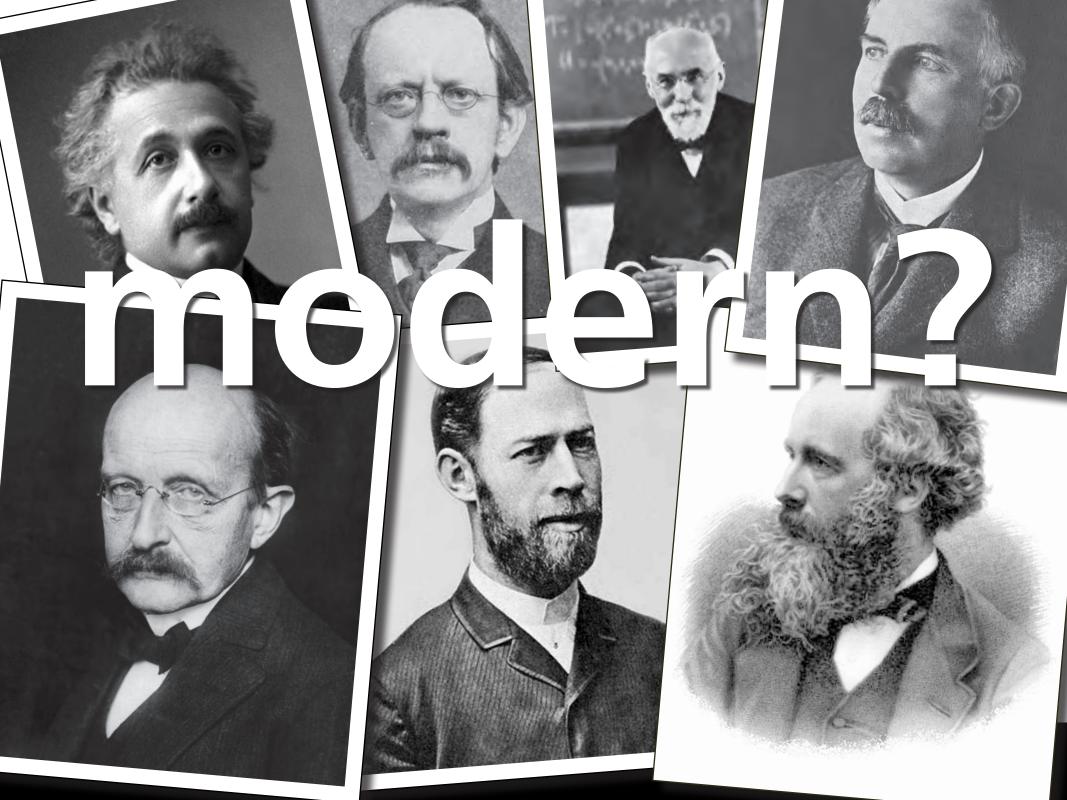
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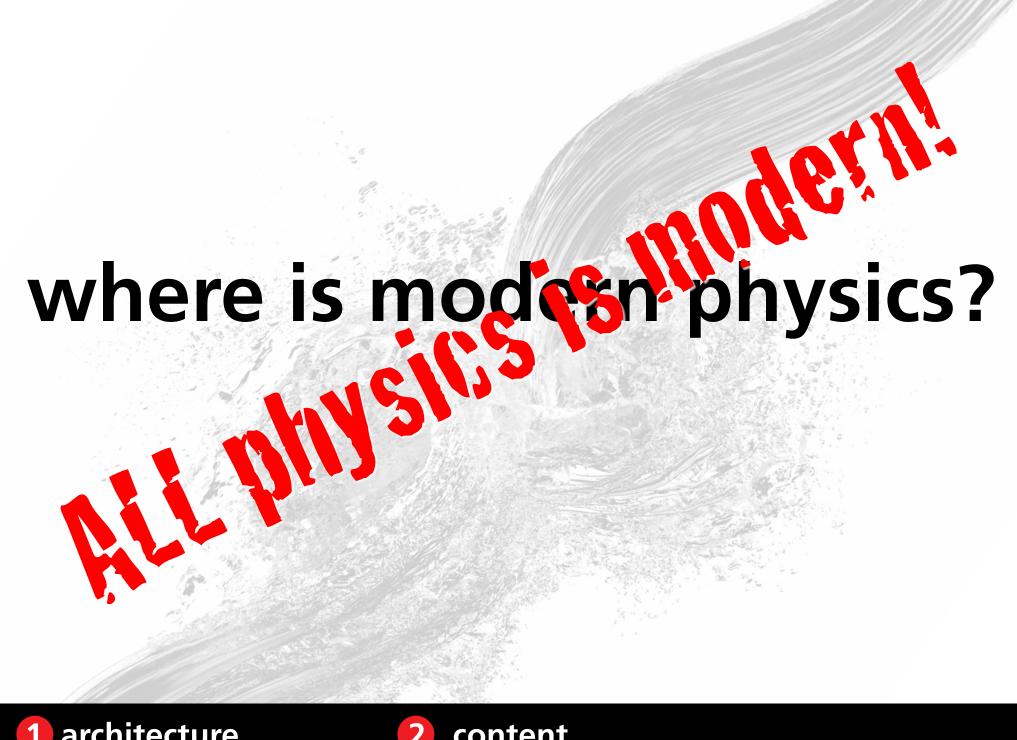


aesthetically more appealing









conservation as modern foundation

- 1. Foundation
- 2. Motion in one
- 3. Acceleration
- 4. Momentum
- 5. Energy
- 6. Principle of relativity
- 7. Interactions
- 8. Force
- 9. Work
- 10. Motion in a plane
- 11. Motion in a circle
- 12. Torque
- 13. Gravity
- 14. Special Relativity
- 15. Periodic Motion
- 16. Waves in one dimension
- 17. Waves in 2 and 3 dimensions

- 18. Fluids
- 19. Entropy
- 20. Energy transferred thermally
- 21. Degradation of energy
- 22. Electric interactions
- 23. The electric field
- 24. Gauss's law
- 25. Work and energy in electrostatics
- 26. Charge separation and storage
- 27. Magnetic interactions
- 28. Magnetic fields of charged particles in motion
- 29. Changing magnetic fields
- 30. Changing electric fields
- 31. Electric circuits
- 32. Electronics
- 33. Ray optics
- 34. Wave and particle optics

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- 3. Accelera
- 4. Momentum interactions

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- 6. Principle of rel
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- 8. Force
- 9. Work
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concepts of

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- 1. Foundations
- 2. Motion in one dimension
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- 5. Energy
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CHAPTER

1

Foundations

Strategy

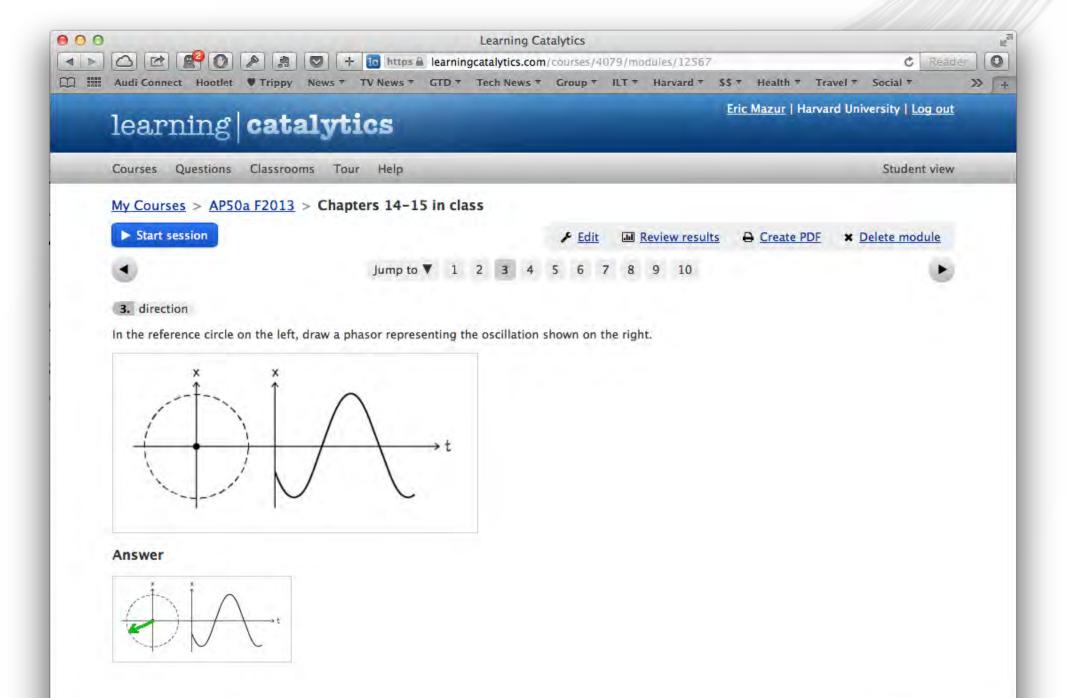
This book is developed with the goal of engaging students in developing a conceptual framework for the topics presented in introductory physics and to develop in students the reasoning and problemsolving skills that will help them in and beyond the study of physics. Throughout this book, the focus is on change, the transition from one state to another. Conservation principles naturally become the focus as they arise from those properties that are observed to remain unchanged. The mathematics requirements are initially minimized to allow students to develop a better grasp of the physics without getting sidetracked by mathematics. For that reason, the first nine chapters only deal with physics in one dimension. Once students have a solid grasp of physics in one dimension, they can better begin to explore two- and three-dimensional problems. This also gives students an opportunity to develop the required math skills in a concurrent mathematics course. Taking mathematics concurrent to physics, rather than as a prerequisite, can increase students' understanding of the mathematical concepts. Further, some concepts are often so transparent to an instructor that they are not taught explicitly, creating difficulty for students who do not have the same background. These foundational ideas, such as symmetry, and tools, such as representations, are spelled out so that students can explicitly engage in their use. Language is used and developed very carefully to avoid introducing confusion. Although they may sometimes seem formal or wordy, these choices have been carefully made to avoid common misconceptions by students.

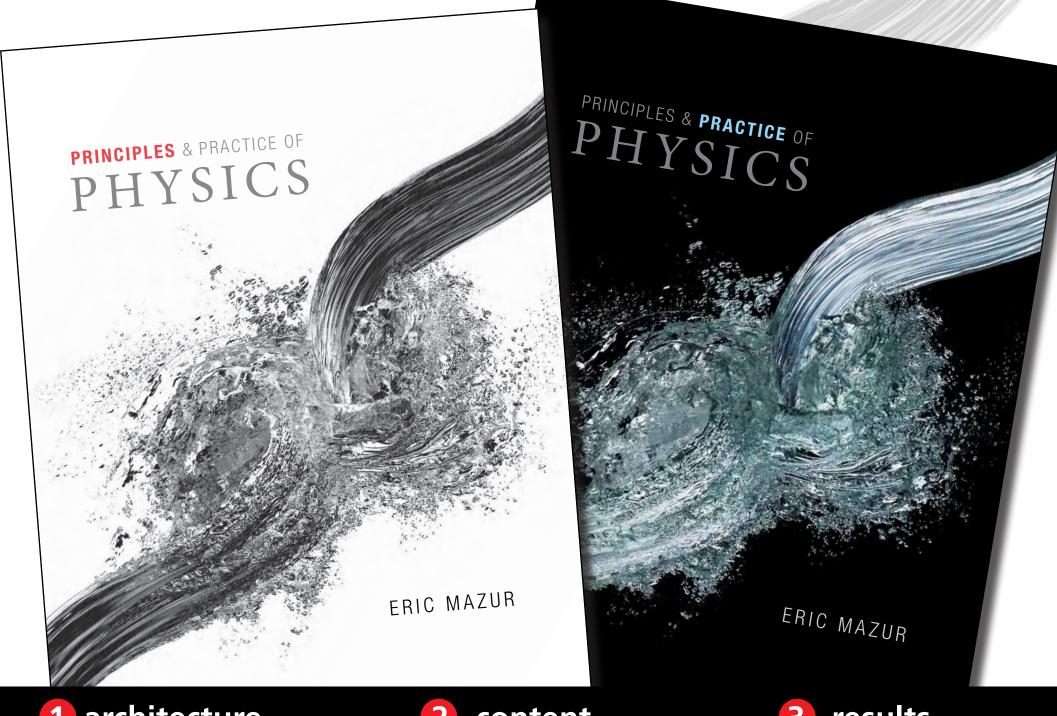
Overview

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- Overview

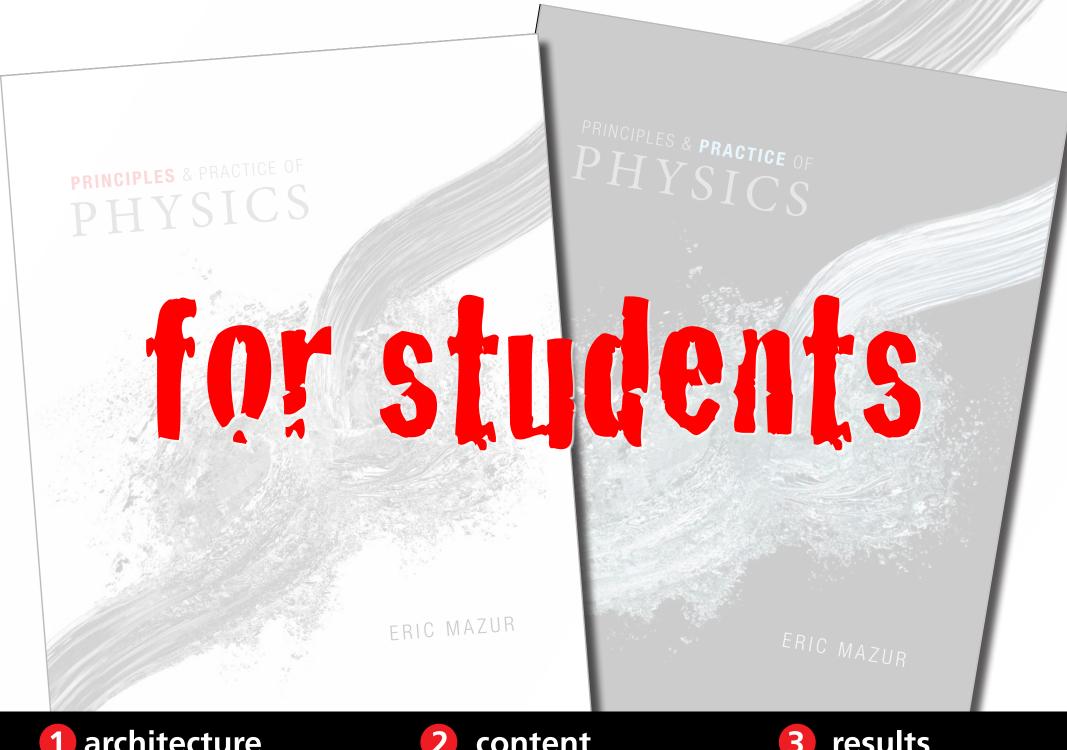
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- Foundations
- Topics that are not covered
- Terminology
- Notation and visual representations
- Cautionary notes
- Common student difficulties and concerns
- Sample recommendations from Practice Vol





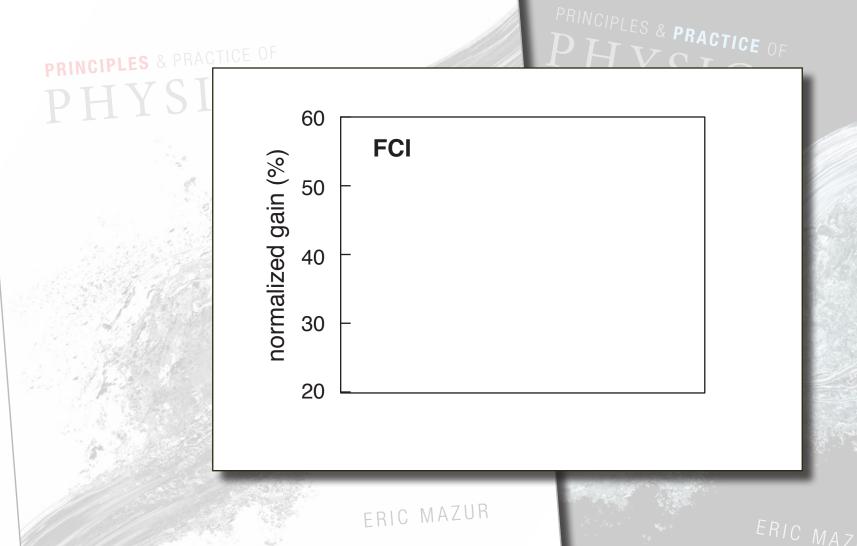
architecture

content



architecture

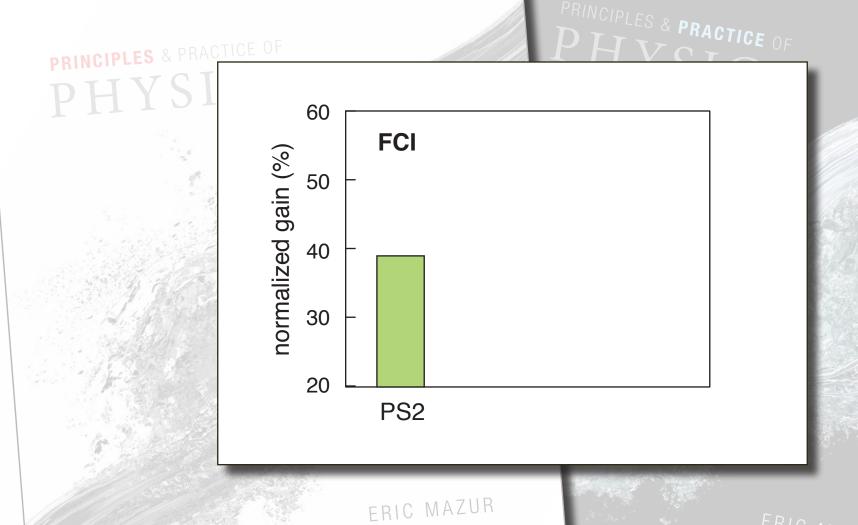
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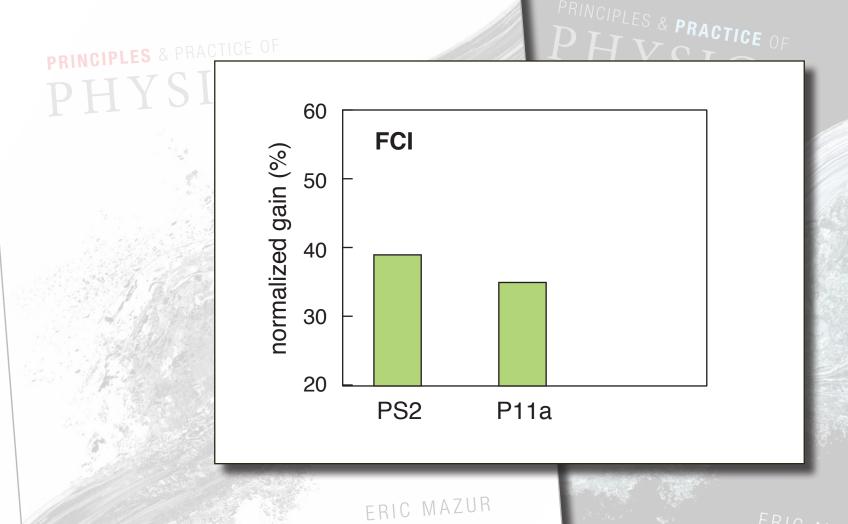






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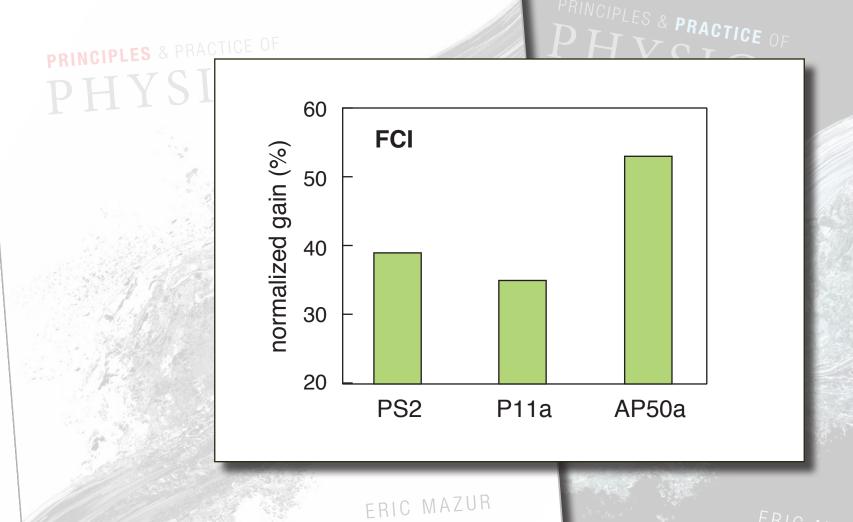
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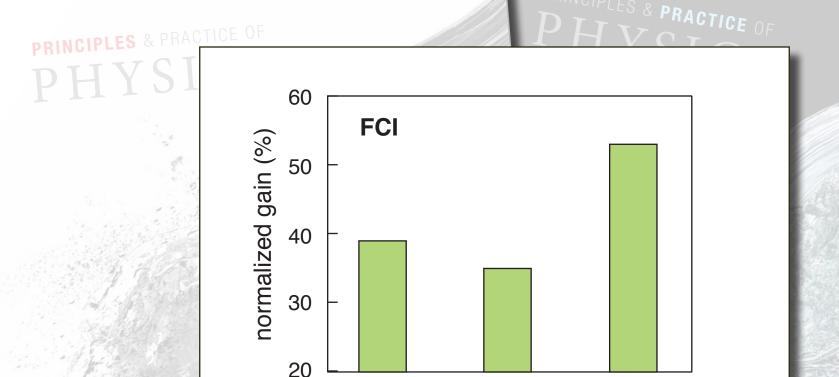










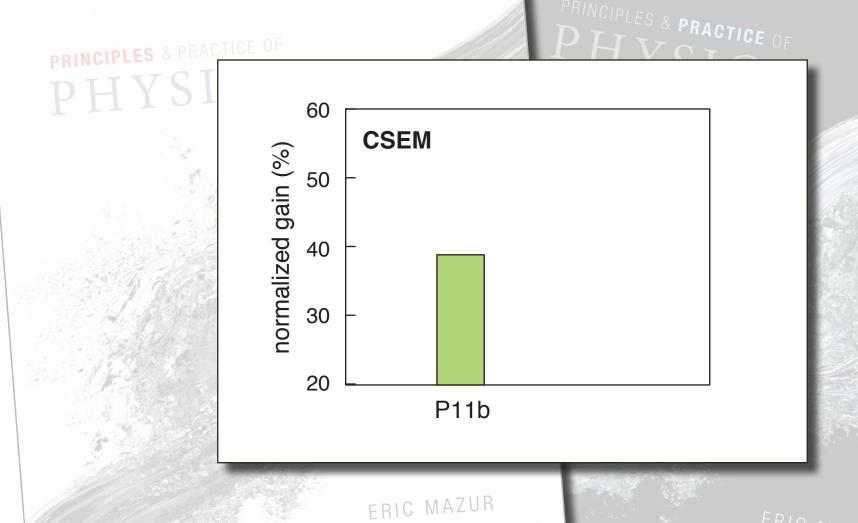


PS2

largest conceptual gain in any course past 6 yrs!

P11a

AP50a

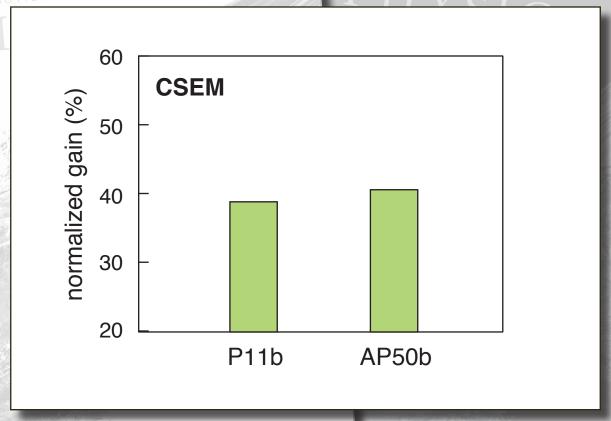


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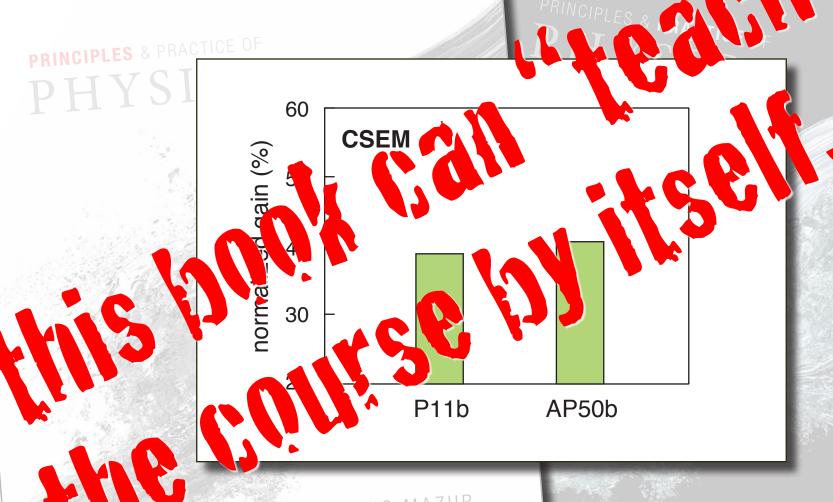
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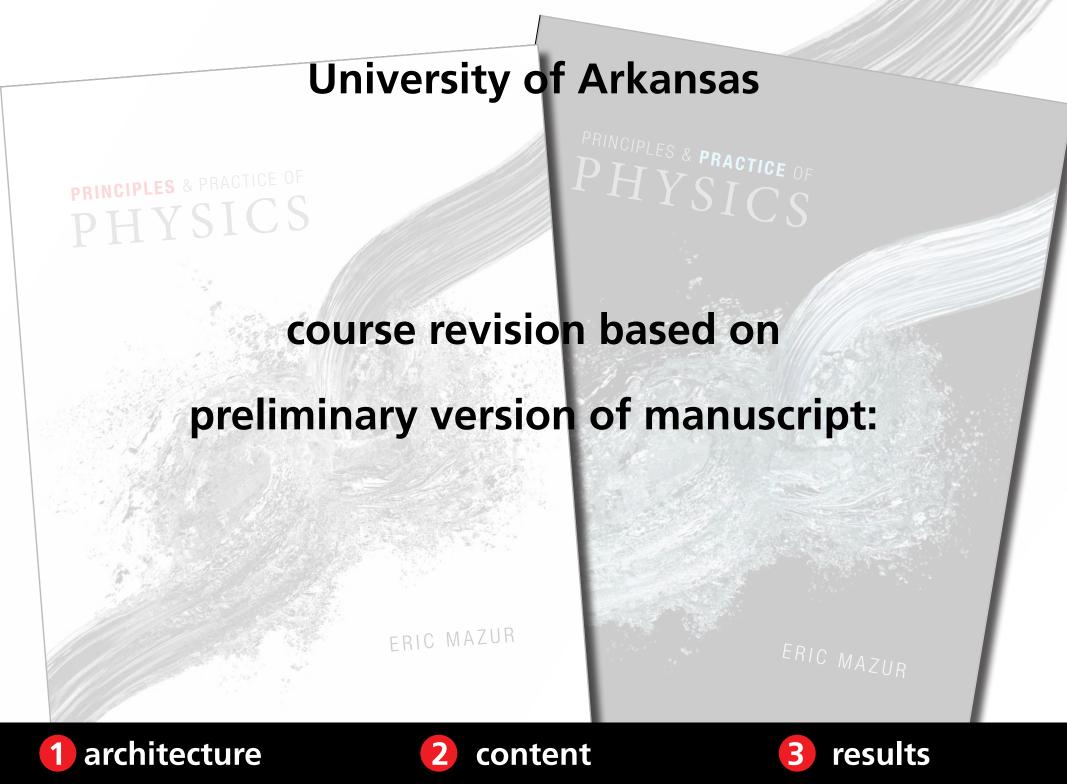
PHYS.



as good as when I do my best teaching!



as good as when I do my best teaching!



University of Arkansas

PRINCIPLES & PRACTICE OF PHYSICS

PHYSICS & PRACTICE OF

course revision based on preliminary version of manuscript: normalized FCI gain DOUBLED

ERIC MAZUR

ERIC MAZIL

Current Adoptions

Abilene Christian University Bellingham Technical College Bethany Lutheran College

Chaffey College

Eastfield College

Embry-Riddle Aera Universit-Prescott

Evergreen State College

Florida State University

Gallaudet University

Gogebic Community College

Harvard University

Highline Community College

Hope College

Ithaca College

James Madison University

Laramie County Community College

Louisiana State University

Monmouth Univiversity

Normandale Community College

Northeastern University

Otterbein University

Penn State University

Siena College

Southwestern Illinois College

Spokane Falls Community College

St Olaf College

Suffolk University RACTI

University of Arkansas

University of Central Florida

University of Florida

University of Connecticut–Storrs

University of Maine at Orono

University of Minnesota

University of Pennsylvania

University of Washington

Victoria College

Virginia Tech University

Washington University

Williams College

John Abbott College (Canada)

Helsinki University (Finland)

McMaster University (Canada)

Monash University (Australia)

Mount Saint Vincent University (Canada)

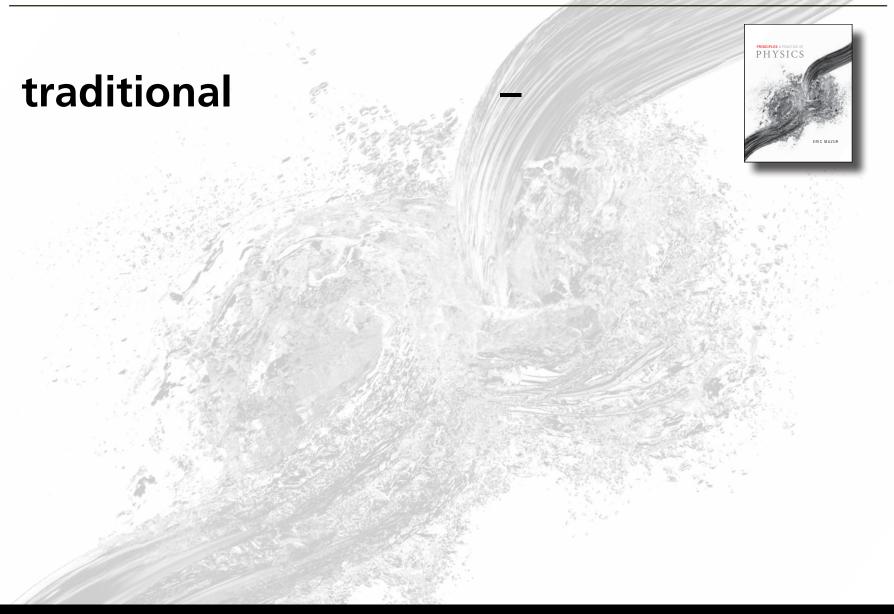
University of British Columbia (Canada)

University of Toronto (Canada)

University of Waterloo (Canada, 2016)

ERIC MAZUR

approach before class in class



before class

in class

traditional



partially flipped

before class

in class

traditional

partially flipped





before class

in class

traditional

partially flipped

fully flipped







before class

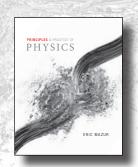
in class

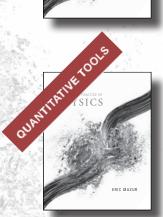
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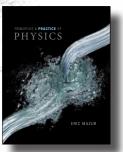
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PRINCIPLES & PRACTICE OF PHYSICS

ericmazur.com

Textbook info/copies: pearsonhighered.com/mazur1einfo

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