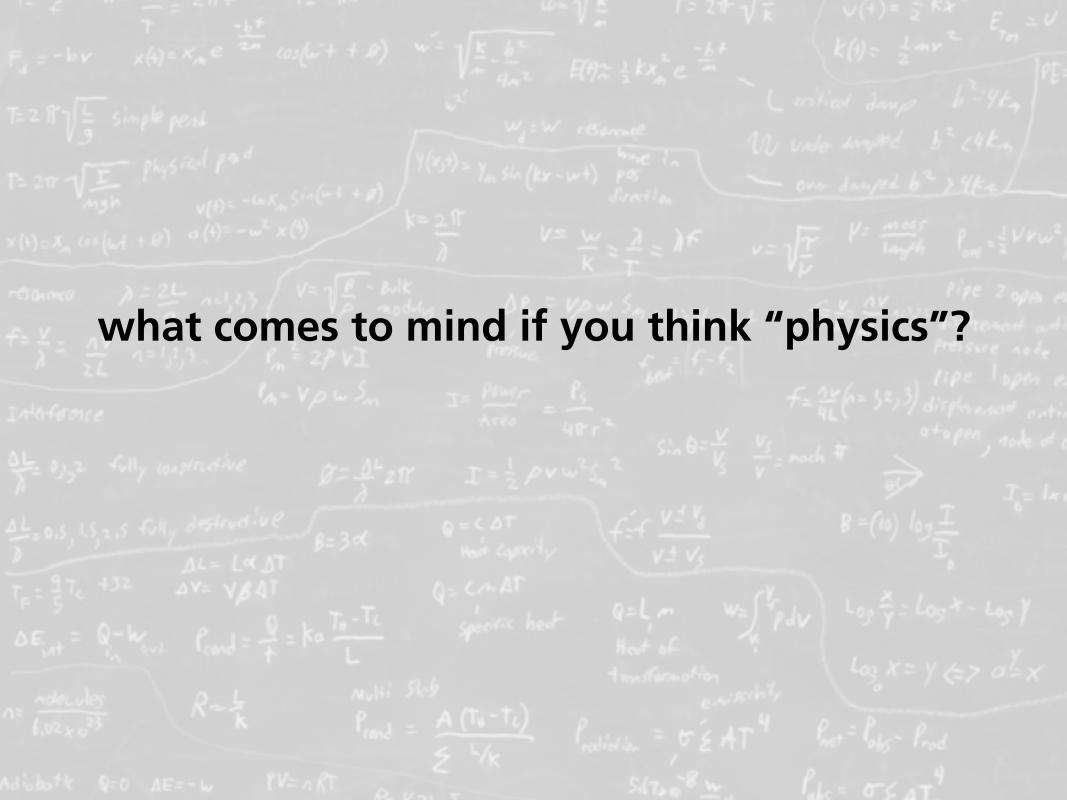
Rethinking Physics





1= 27 VE k(1)= 2 KX ET = V Ceritical Jamp 6-4ta PE T=217 = simple pend W=W resource No under sampled b2 (4km) T= 2TT VI physical pad

with= -wx Y(xst) = Ym sta (kx-wt) pos direction - over danged be >4kal v(+)=-wx, sin(w++p) x(+)= x, (05 (w++8) 0 (+)=-w2 x(+) V= VI P= moss Pore = 2 VVW2 V= W= A= IF resonance 1= 2L nels, = V= VB - Bulk modulus Pipe 2 open es DPm = Vpw Sm · displacement f= v AV 123 displacement and f= = 1 = 1,2,3 Pm = 2PVI I = Power = Ps best fi-fz pressure node lipe lopen e. f= 1/(n= 12,3) displacement ontin Pm= Vp w Sm Interferonce atopen, note of a I = 1 pv w25, 2 Sin 0 = V/5 V/5 = moch # To 0352 fully constructive Ø= DL zir In= lan AL= 0.5, 1.5, 2.5 fully destructive B = (10) log I Q=CAT B=3d Host Copacity AL= La DI TE= 976 +32 Q= CMAT AV= VBAT W= Stpdv Q=Lm Los 7 = Lost - Los y specific heat DE int = Q-Would Prond = + = ka T+-Tc Hest of Log x = y (= > 0= x transformation Multi Slob n= holecules Prond = A (Tu-ta) Pret = Pobs - Prod rediction = 5 EAT4 2 1/k 567208 W Pals = 05 AT Adiobotic Q=0 AE=-W PV=nRT Qual F



Halliday / Resnick / Walker
PHYSICS

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COLLEGE PHYSICS

why is it that physics evokes these emotions?

- COLUTIONS MANUAL AND STUDY GOLD

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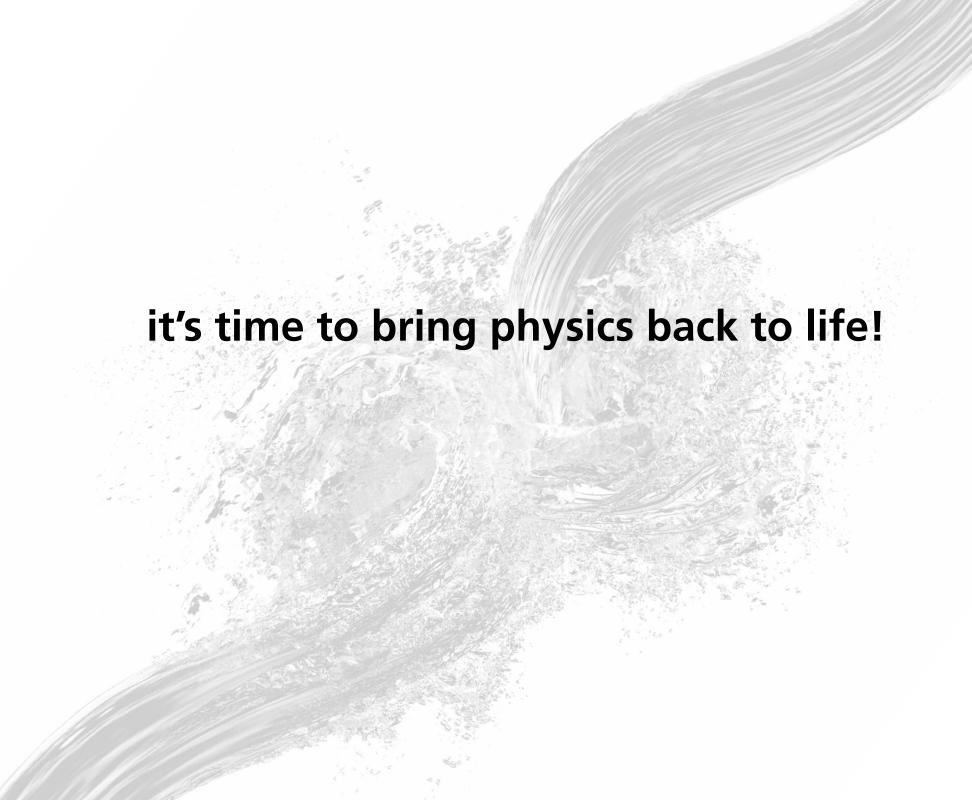
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AND ENGINEERS

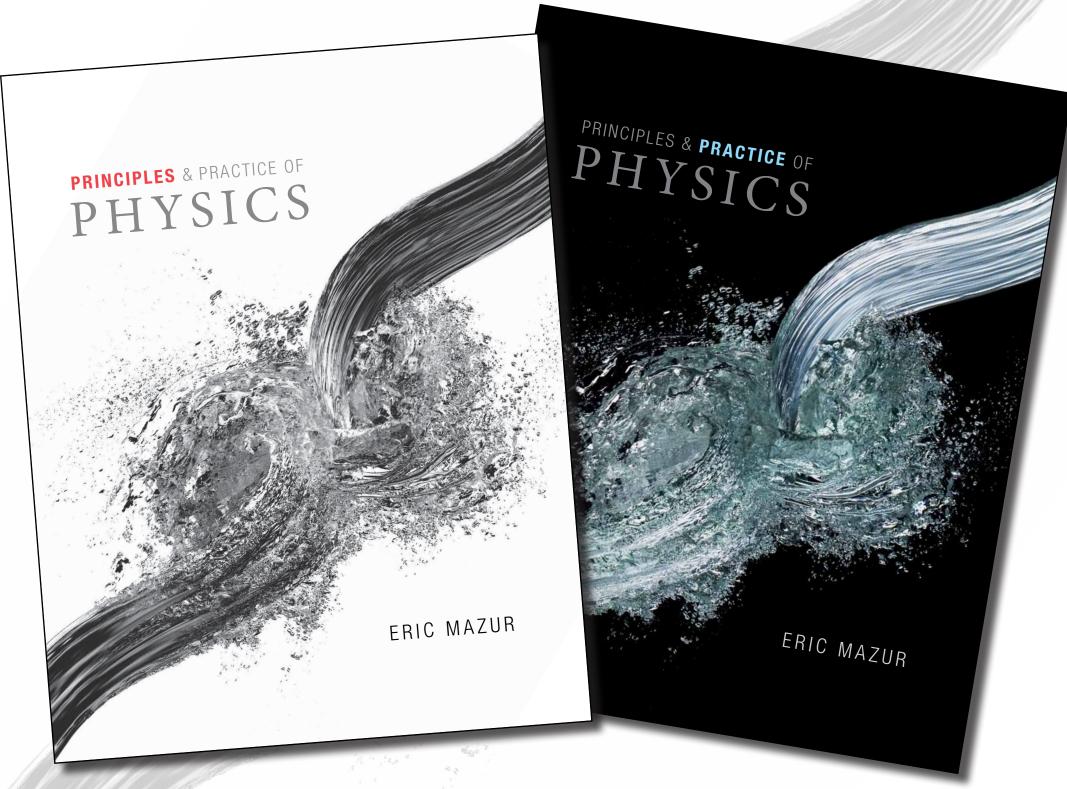
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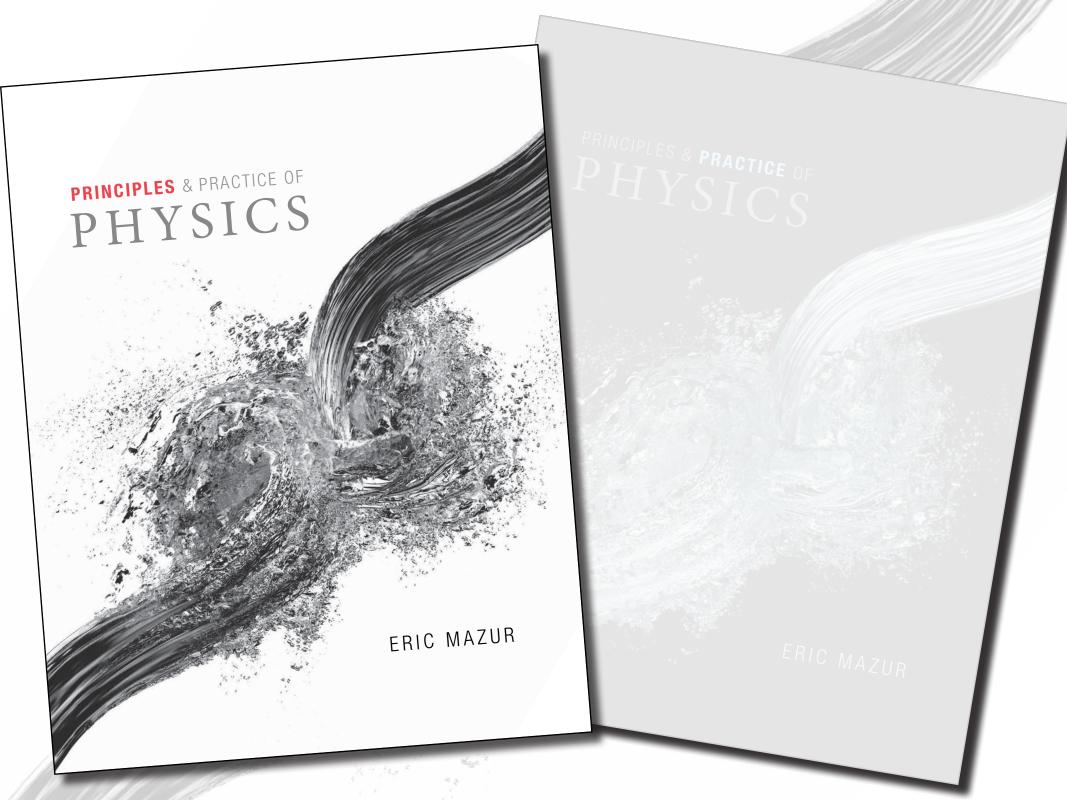
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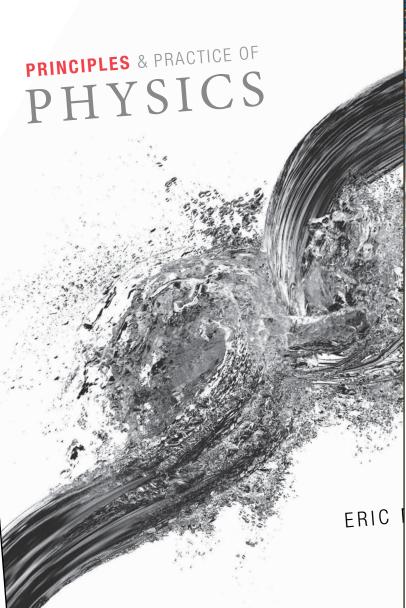


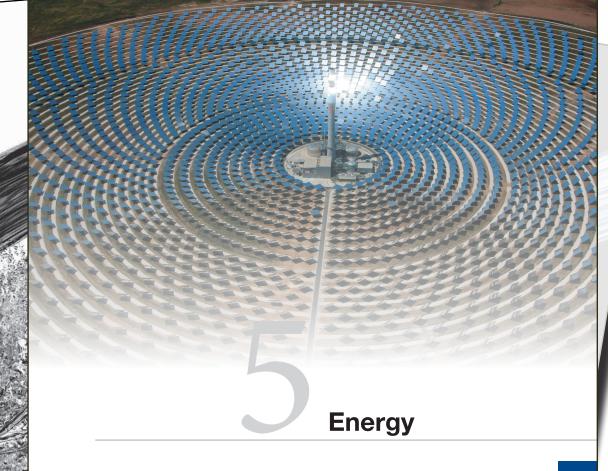




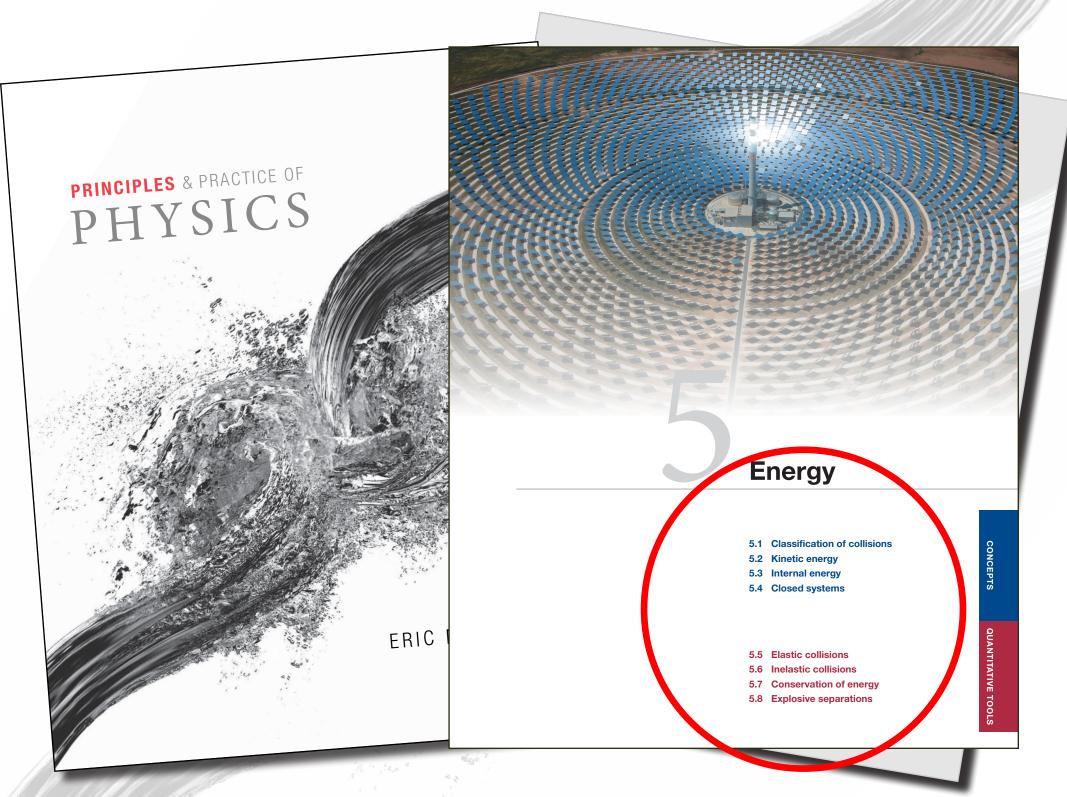


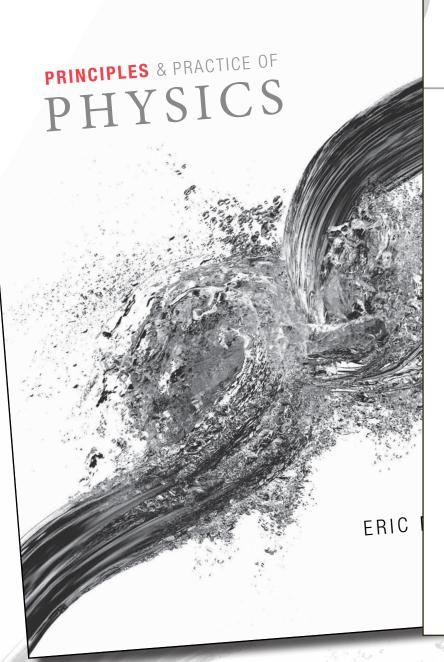






- 5.1 Classification of collisions
- 5.2 Kinetic energy
- 5.3 Internal energy
- 5.4 Closed systems
- 5.5 Elastic collisions
- 5.6 Inelastic collisions
- 5.7 Conservation of energy
- 5.8 Explosive separations

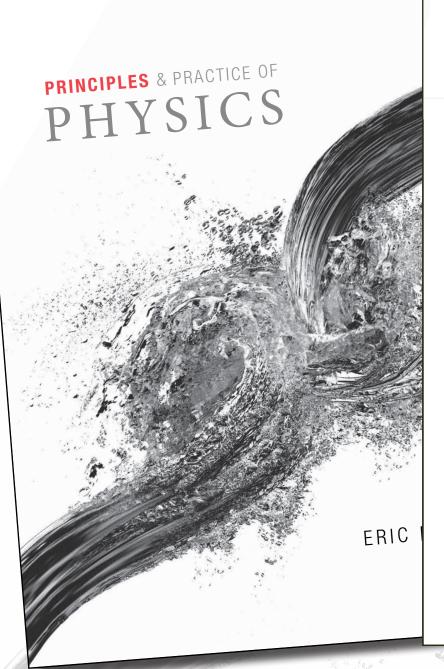




Energy

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CONCEPTS

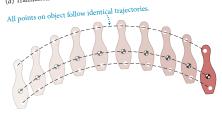
eparations

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



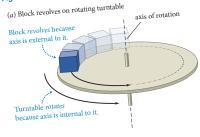


motion. We therefore begin our analysis of rotational motion by describing circular motion. Circular motion occurs all around us. A speck of dust stuck to a spinning CD, a stone being whirled around on a string, a person on a Ferris wheel—all travel along the perimeter of a circle, repeating their motion 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.

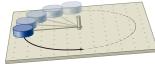
11.1 Circular motion at constant speed

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



energy vstems 11.1 Circular motion at constant speed

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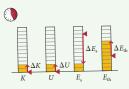
SFLF-QUIZ

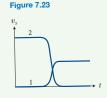
cation of collisions energy energy systems

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?

Figure 7.22

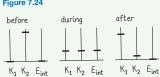




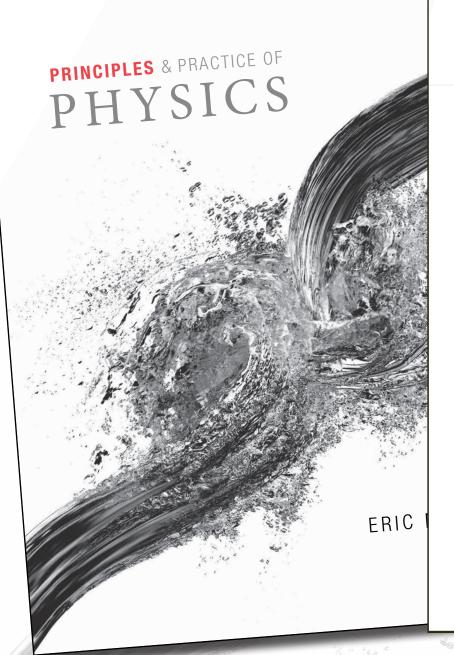
5. Describe a scenario to fit the velocity-versus-time curves for two colliding objects shown in Figure 7.23. What happens to the initial energy of the system of colliding objects during the interaction?

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 $E_{\text{int}} = 0$; 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.



- 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.



Energy

- 5.1 Classification of collisions
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QUANTITATIVE TOOLS

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:

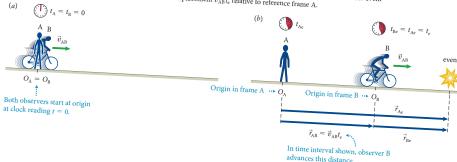
$$t_{\rm A} = t_{\rm B} = t. \tag{6.2}$$

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 $\Delta t = t_{\rm e} - 0 = t_{\rm e}$, and so $\vec{r}_{\rm AB} = \vec{v}_{\rm AB} t_{\rm e}$ because B moves at constant velocity $\vec{v}_{\rm AB}$. Therefore

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

build to Conceptual Because the clock readings of the two observers always agree, we can omit the

From Figur 61: nderfood ence frame A Unit de fis Distribution of the first $\Delta t = t_{r} - 0 = t_{r}$, and so $r_{AR} = v_{AR} t_{r}$ becaute B moves at constant velocity

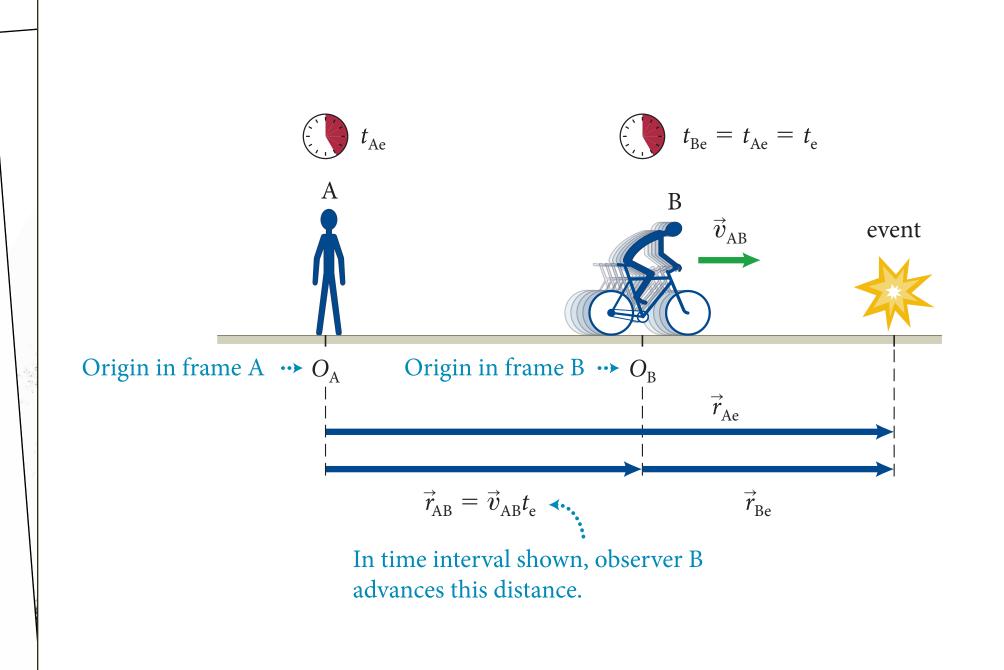
$$\vec{r}_{Ae} = \vec{r}_{AB} + \vec{r}_{Be} = \vec{v}_{AB} t_e + \vec{r}_{Be}.$$
 (6.3)

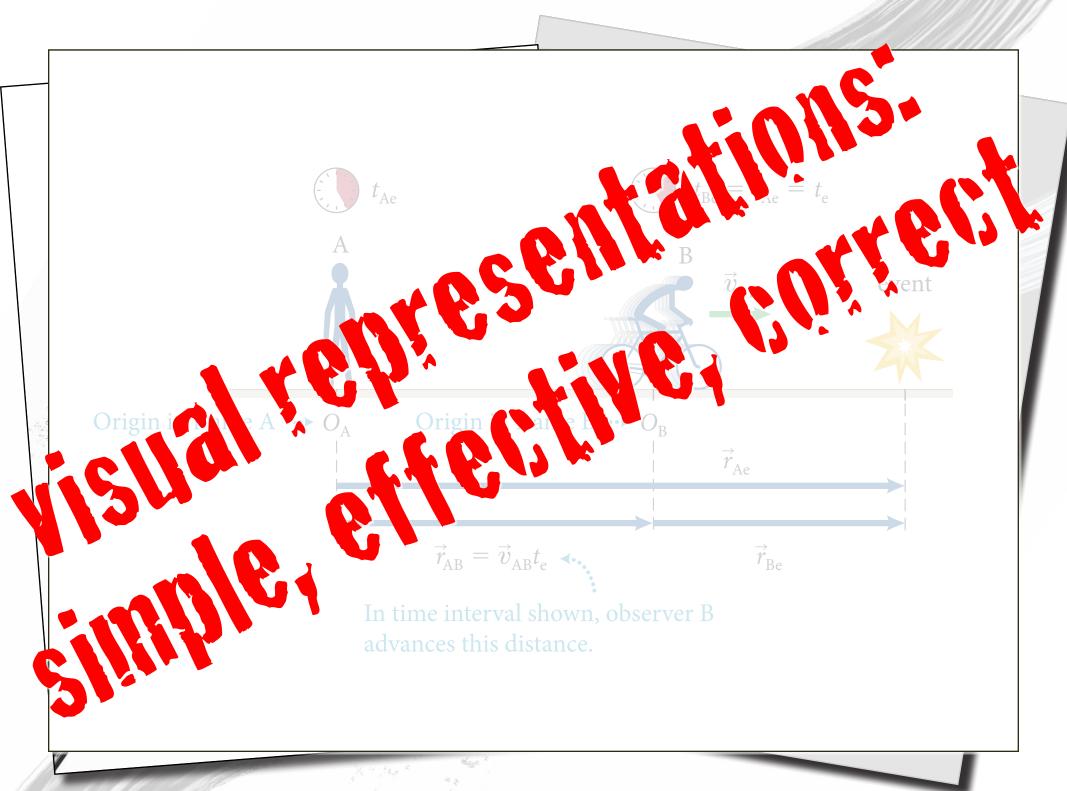
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PRINCIPLES & PRACTICE OF

6.5 Galilean relativity

Consider two observers, A and B, moving at constant velocity relative to each hand to be good by the consideration of the two hands of the consideration of the two hands of the three constant position \vec{r}_{Ae} at clock reading t_{Ae} (Figure 6.13b).* Observer B sees the event as happening at position \vec{r}_{Be} at clock reading t_{Be} . What is the relationship between these clock readings and positions?

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$$t_{\Delta_o} = t_{R_o}. (6.1)$$

distinguishing features

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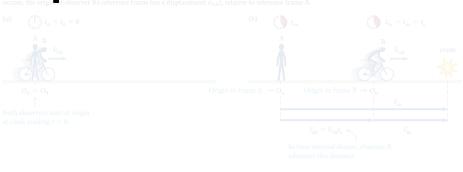
focus on conservation principles

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.

concepts before quantitative tools

• 1D before 3D

ERIC

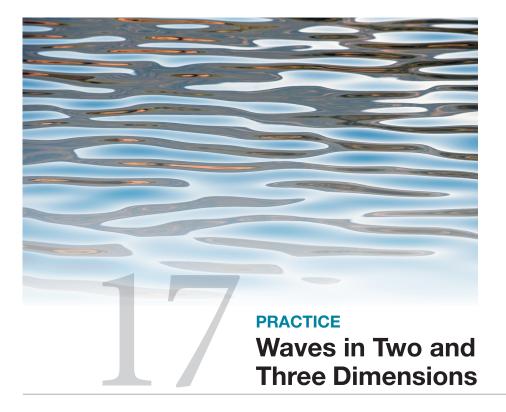


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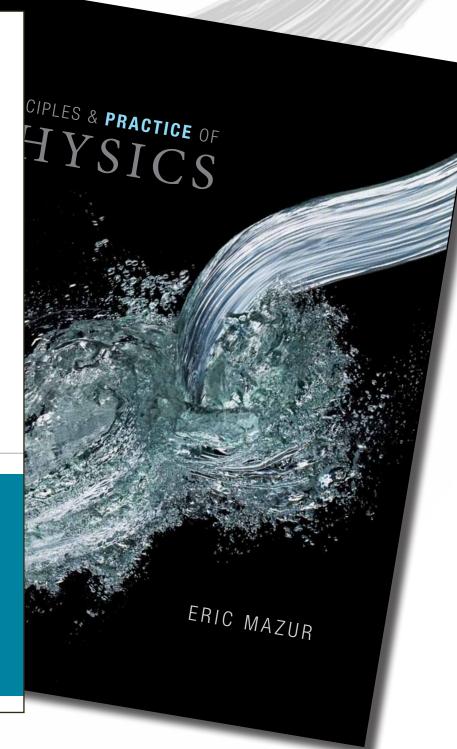
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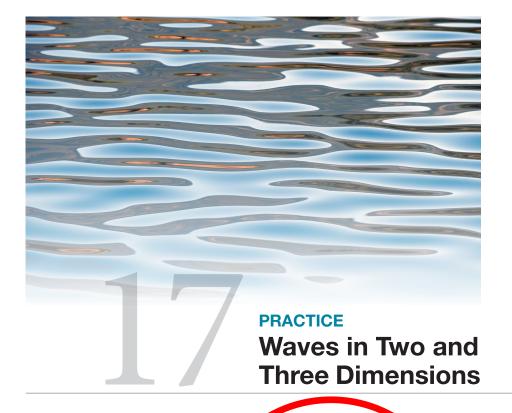
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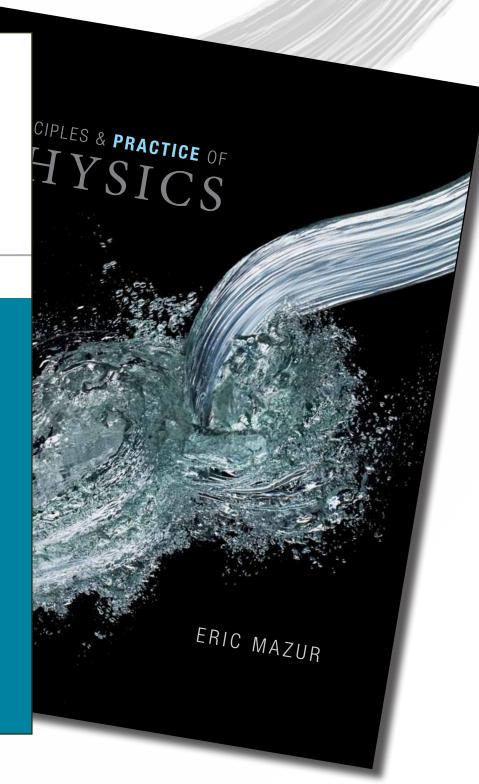
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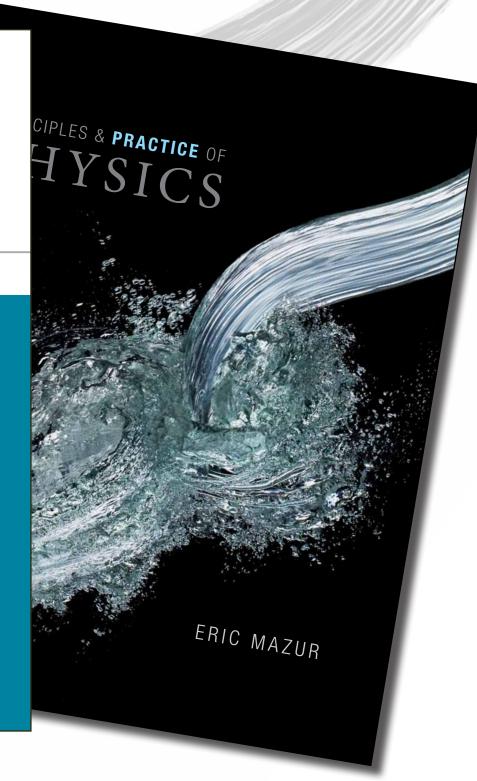
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Developing a Feel

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?
- V. What is your inertia?
- 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; $K.6 \times 10^{-5}$ 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. $\omega \approx 10~\text{s}^{-1};~V.7 \times 10^1$ kg; W. 0.5 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 Three Dimens

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192 CHAPTER 11 PRACTICE MOTION IN A CIRCLE

Developing a Feel

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- 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)
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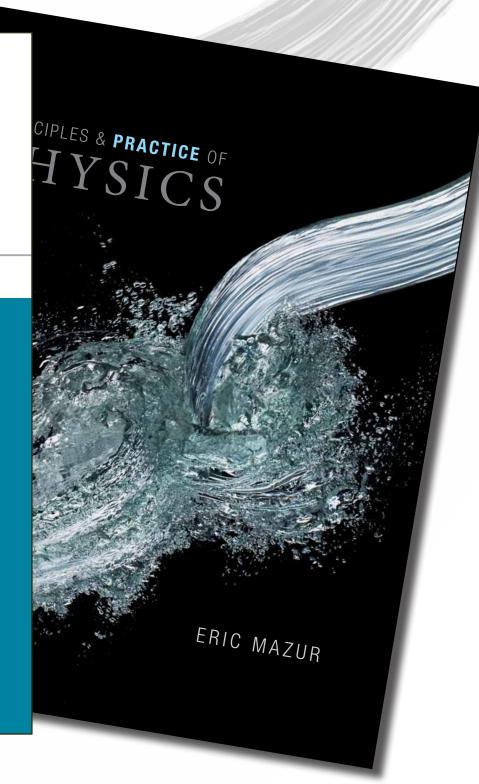
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Worked Problem 13.3 Escape at last

The Mars Colony wants to launch a deep-space probe, but they have no rocket engines. They decide to launch a probe with an electromagnetic cannon, which means they must launch at escape speed.

• GETTING STARTED Let us do a quick sketch to help our thinking (Figure WG13.3). We select the Mars-probe system for analysis. In order to reach "deep space," the probe must attain a very great distance from Mars. This will require a significant amount of initial kinetic energy, which the probe must acquire during launch. After launch, the kinetic energy immediately begins to decrease, and the potential energy of the Mars-probe system increases as the separation distance increases. We assume a reference frame where Mars is fixed and only the probe moves. When the probe is far enough away (infinity, really, but practically it doesn't need to go quite this far), the kinetic energy has its minimum value, which we can take to be zero because the colonists presumably do not want to supply any more energy than needed to get the probe out there. The gravitational potential energy has its maximum value, which is also zero. (Remember that universal gravitational potential energy is negative.) We also assume that the Sun and other planets have a negligible influence on our system, and we ignore the rotation of Mars.



2 DEVISE PLAN We can use conservation of energy because the probe has all of the needed kinetic energy at the beginning, as it is shot from a cannon. As the probe travels, this kinetic energy is converted to gravitational potential energy of the Mars-probe system. We want to know the initial speed of the probe acquired at launch. The initial potential energy is the value when the probe is still near the Martian surface. The final state of the probe is zero speed at an infinite distance from Mars. The Principles volume analyzes a similar situation in Section 13.7, leading to Eq. 13.23, so there is no need to derive this result again here. We begin with Eq. 13.23, solving this version of an energy conservation equation for $v_{\rm i}=v_{\rm esc}$ in terms of

Guided Problem 13.4 Spring to the stars

Suppose that, instead of using chemical rockets, NASA decided to use a compressed spring to launch a spacecraft. If the spring constant is 100,000 N/m and the mass of the spacecraft is 10,000 kg, how far must the spring be compressed in order to launch the craft to a position outside Earth's gravitational influence?

1 GETTING STARTED

- Describe the problem in your own words. Are there similarities
- 2. Draw a diagram showing the initial and final states. What is the spacecraft's situation in the final state?
- 3. How does the spacecraft gain the necessary escape speed?

2 DEVISE PLAN

4. What law of physics should you invoke?

3 EXECUTE PLAN Let us use r_i for the initial Mars-probe radial center-to-center separation distance, $r_1 = \infty$ for the final separation distance, $R_{\rm M}$ for the radius of Mars, and $m_{\rm M}$ and $m_{\rm p}$ for the two masses. We begin with Eq. 13.23:

$$\begin{split} E_{\rm mech} &= \tfrac{1}{2} m_{\rm p} v_{\rm esc}^2 - G \frac{m_{\rm M} m_{\rm p}}{R_{\rm M}} = 0 \\ & \tfrac{1}{2} v_{\rm esc}^2 - G \frac{m_{\rm M}}{R_{\rm M}} = 0 \\ & \tfrac{1}{2} v_{\rm esc}^2 = G \frac{m_{\rm M}}{R_{\rm M}} \\ & v_{\rm esc} = \sqrt{2G \frac{m_{\rm M}}{R_{\rm M}}} \\ v_{\rm esc} &= \sqrt{2(6.67 \times 10^{-11} \, \mathrm{N} \cdot \mathrm{m}^2/\mathrm{kg}^2) \frac{6.42 \times 10^{23} \, \mathrm{kg}}{3.40 \times 10^6 \mathrm{m}}} \\ &= 5.02 \times 10^3 \, \mathrm{m/s} = 5 \, \mathrm{km/s}. \end{split}$$

Notice that this speed does not depend on the mass of the probe. A probe of any other size shot from the cannon would need the same minimum speed to break free of Mars's gravitational pull.

4 EVALUATE RESULT Our algebraic expression for the escape speed is plausible because it involves the mass of Mars, the initial center-to-center radial separation distance of our two objects (which is Mars's radius), and G. We expect $v_{\rm esc}$ to increase with $m_{\rm M}$ because the gravitational pull increases with increasing mass. We also expect $v_{\rm esc}$ to decrease as the distance between the launch position and Mars's center increases because the gravitational force exerted by the planet on the probe decreases with increasing separation distance. All this is just what our result predicts.

An escape speed of 18,000 km/h is smaller than (but on the order of) the escape speed from Earth, and so the answer is not unreasonable.

We assumed that the initial Mars-probe separation distance is equal to the planet's radius. Of course, the length of the cannon may be tens of meters, but this tiny difference would have no impact on the numerical answer. We ignored the rotation of Mars, which could supply a small amount of the needed kinetic energy. We also ignored the effect of the Sun, which is fine for getting away from the surface of Mars, but we would need to account for it if the destina-

5. As the spring is compressed, is the gravitational potential energy of the Earth-spacecraft system affected? If so, can you

6. What equation allows you to relate the initial and final states?

3 EXECUTE PLAN

- 7. What is your target unknown quantity? Algebraically isolate it on one side of your equation.
- 8. Substitute the numerical values you know to get a numerical

4 EVALUATE RESULT

- 9. Is your algebraic expression for the compression plausible for how the compression changes as the spring constant and Earth's mass and radius change?
- 10. If you were the head of a design team, would you recommend pursuing this launch method?

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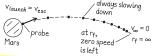
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Questions and Problems 311 **Answers to Review Questions Answers to Guided Problems 316** 238 CHAPTER 13 PRACTICE GRAVITY

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- 2. Draw a diagram showing the initial and final states. What is the spacecraft's situation in the final state?
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2 DEVISE PLAN

4. What law of physics should you invoke?

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$$\begin{split} E_{\rm mech} &= \tfrac{1}{2} m_{\rm p} v_{\rm esc}^2 - G \frac{m_{\rm m} m_{\rm p}}{R_{\rm M}} = 0 \\ &\tfrac{1}{2} v_{\rm esc}^2 - G \frac{m_{\rm m}}{R_{\rm M}} = 0 \\ &\tfrac{1}{2} v_{\rm esc}^2 = G \frac{m_{\rm m}}{R_{\rm M}} \\ &v_{\rm esc} = \sqrt{2 G \frac{m_{\rm m}}{R_{\rm M}}} \\ v_{\rm esc} &= \sqrt{2 (6.67 \times 10^{-11} \, {\rm N} \cdot {\rm m}^2/{\rm kg}^2) \frac{6.42 \times 10^{23} \, {\rm kg}}{3.40 \times 10^6 \, {\rm m}}} \\ &= 5.02 \times 10^3 \, {\rm m/s} = 5 \, {\rm km/s}. \end{split}$$

Notice that this speed does not depend on the mass of the probe. A probe of any other size shot from the cannon would need the same minimum speed to break free of Mars's gravitational pull.

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We assumed that the initial Mars-probe separation distance is equal to the planet's radius. Of course, the length of the cannon may be tens of meters, but this tiny difference would have no impact on the numerical answer. We ignored the rotation of Mars, which could supply a small amount of the needed kinetic energy. We also ignored the effect of the Sun, which is fine for getting away from the surface of Mars, but we would need to account for it if the destina-

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- 9. Is your algebraic expression for the compression plausible for how the compression changes as the spring constant and Earth's mass and radius change?
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Waves in Two a **Three Dimension**

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Worked and Guided Problems

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Worked Problem 13.3 Escape at last

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PRACTICE Waves in Two a **Three Dimension**

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Developing a Feel 306

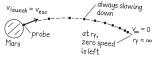
Worked and Guided Problems

Questions and Problems 311 **Answers to Review Questions Answers to Guided Problems 316** 238 CHAPTER 13 PRACTICE GRAVITY

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PRACTICE

Waves in Two a **Three Dimension**

Chapter Sum

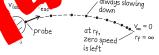
Guided Problems

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Waves in Two distinguishing features

PRACTICE

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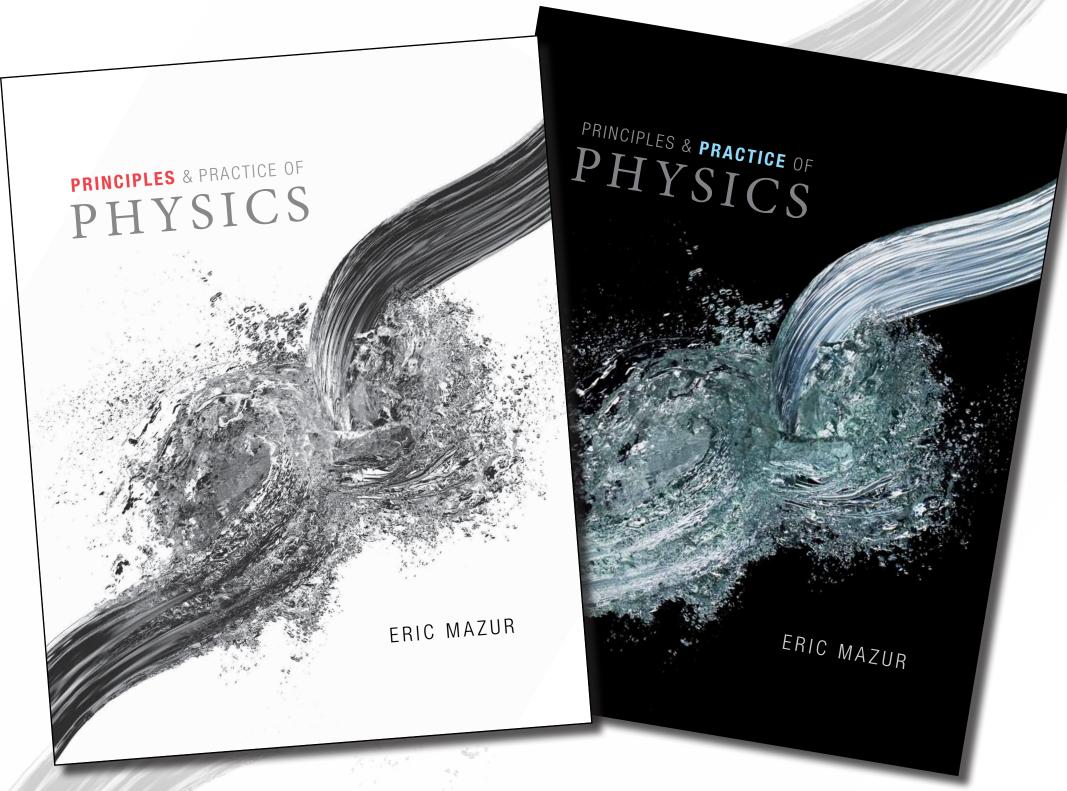
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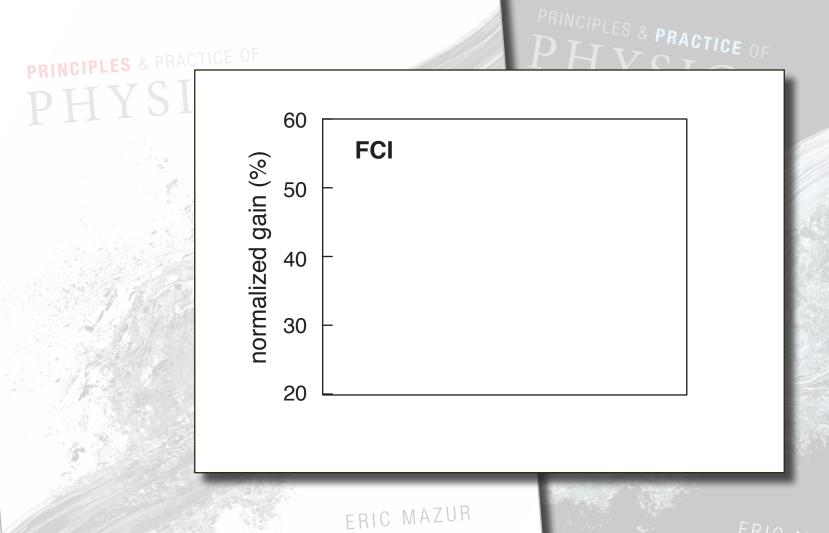
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many innovative features

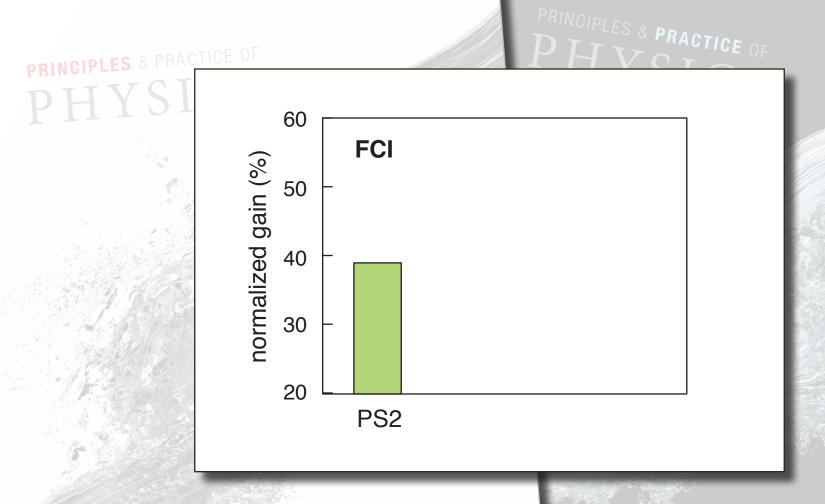
teaches authentic problem solving



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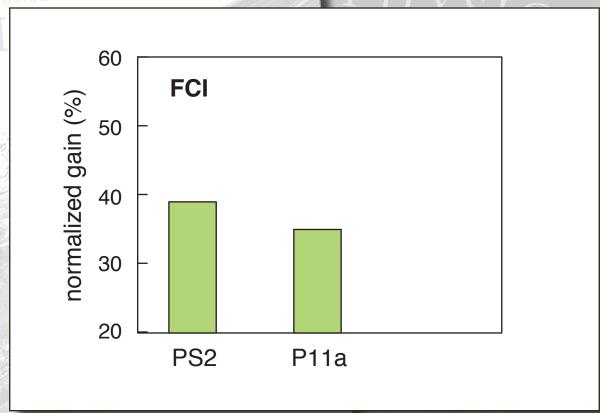


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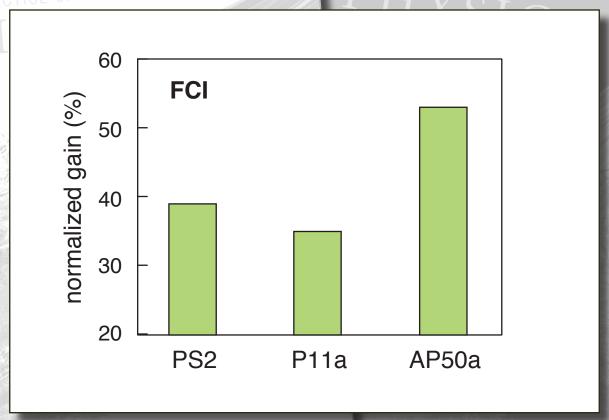


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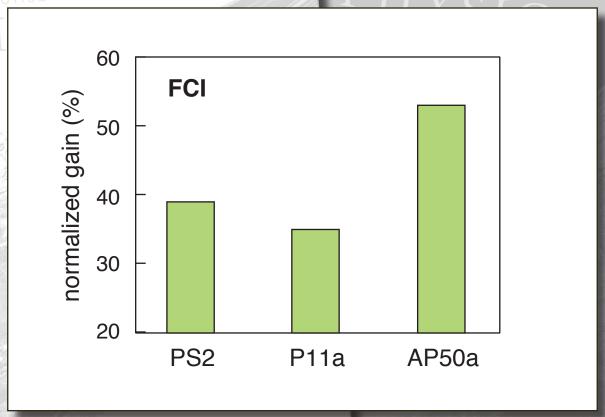


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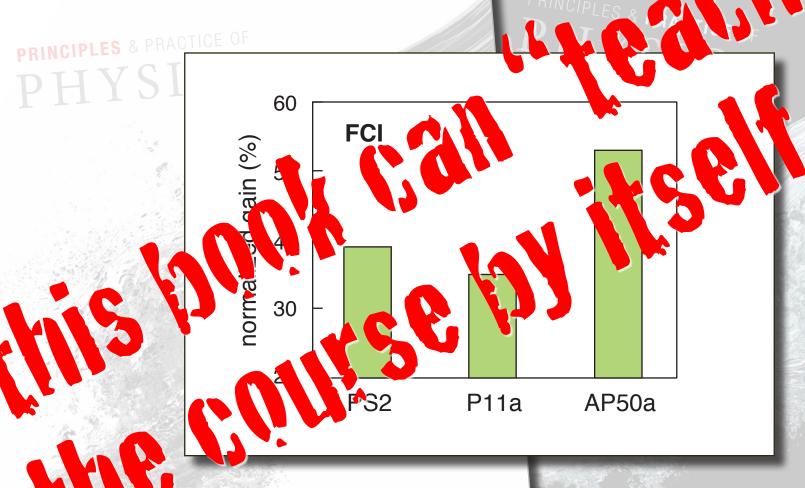






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Thank you for your work — stay in touch!

PRINCIPLES & PRACTICE OF PHYSICS

mazur@harvard.edu

mazur.harvard.edu

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