Welcome online! Before we start:

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Teaching Physics, Conservation Laws First

Webinar
26 January 2016

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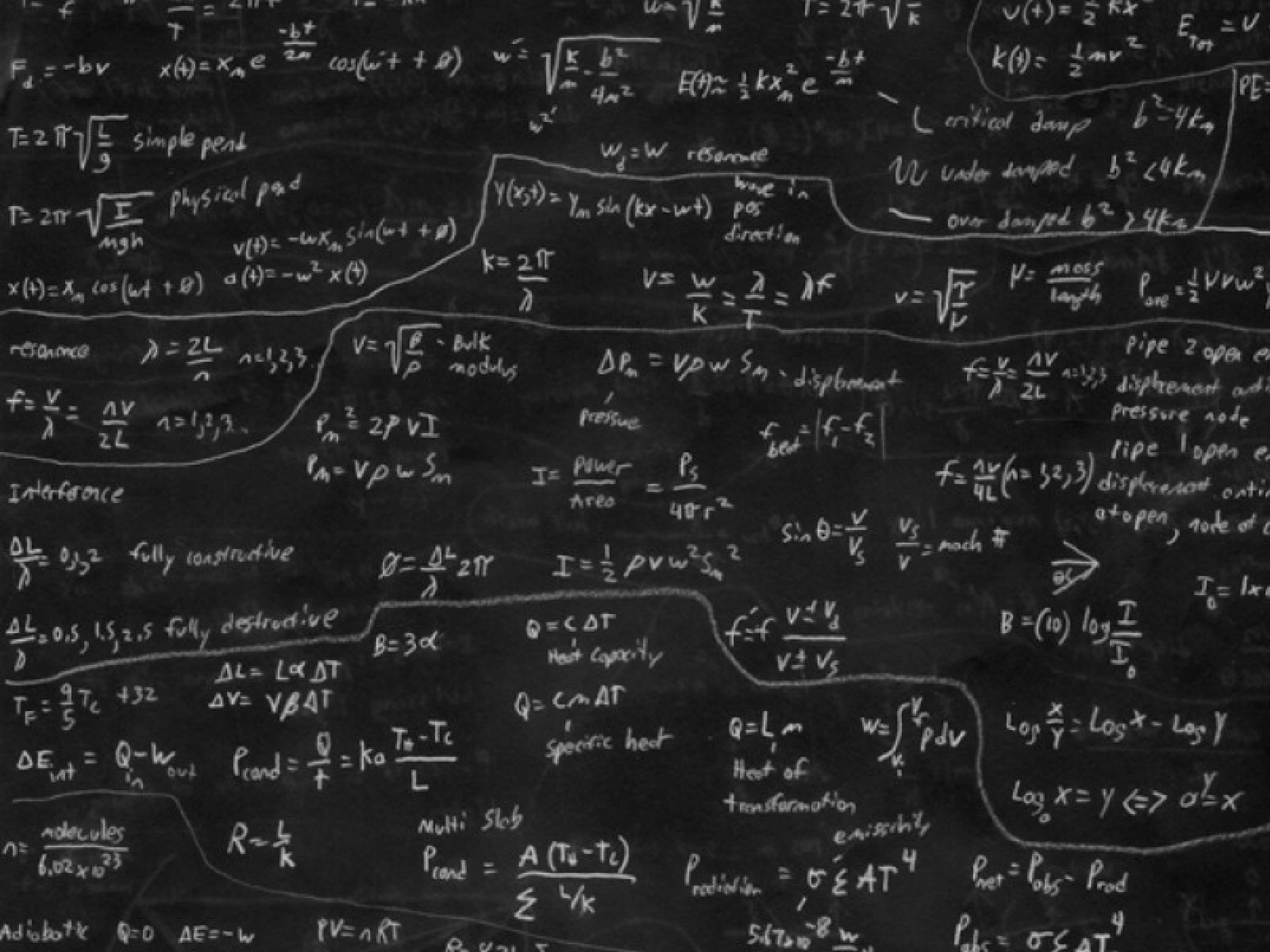
26 January 2016



F_d = -bv
x(t) = x_m e^(-bt/2m) cos(w't + ø)
w' = √(k/m - b²/4m²)
E(t) ≈ ½kx_m² e^(-bt/m)
T = 2π√(L/g) simple pend
T = 2π√(I/mgh) physical pend
critical damp b² = 4km
under damped b² < 4km
over damped b² > 4km
w_d = w resonance
y(x,t) = y_m sin(kx - wt) wave in pos direction
v(t) = -wx_m sin(wt + ø)
a(t) = -w² x(t)
x(t) = x_m cos(wt + ø)
k = 2π/λ
v = w/k = λ/T = λf
v = √(τ/μ)
μ = mass/length
P_ave = ½μvw²
resonance λ = 2L/n n=1,2,3
f = v/λ = nv/2L n=1,2,3
v = √(β/ρ) β bulk modulus
ΔP_m = vρw s_m displacement, pressure
f = v/λ = nv/2L n=1,2,3
pipe 2 open
displacement
pressure node
pipe 1 open
f = nv/4L (n = 1,3,5)
displacement
at open, node
P_m² = 2ρvI
P_m = vρw s_m
f_beat = |f_1 - f_2|
I = power/Area = P_s/4πr²
Interference
sin θ = v/v_s
v_s/v = mach #
ΔL/λ = 0,1,2 fully constructive
ø = ΔL/λ 2π
I = ½ρvw²s_m²
ΔL/λ = 0.5, 1.5, 2.5 fully destructive
B = 3α
Q = C ΔT Heat capacity
f' = f (v ± v_d)/(v ± v_s)
B = (10) log I/I_0
ΔL = Lα ΔT
ΔV = Vβ ΔT
T_F = 9/5 T_C + 32
Q = cm ΔT specific heat
Q = L m Heat of transformation
W = ∫ p dV
Log x/y = Log x - Log y
ΔE_int = Q_in - W_out
P_cond = Q/t = kA (T_H - T_C)/L
Log_a x = y ⇔ a^y = x
n = molecules/6.02×10²³
R = L/k
Multi Slab
P_cond = A(T_H - T_C)/Σ L/k
emissivity
P_radiation = σεAT⁴
P_net = P_abs - P_rad
Adiabatic Q=0 ΔE = -W
PV = nRT
P_abs = σεAT⁴

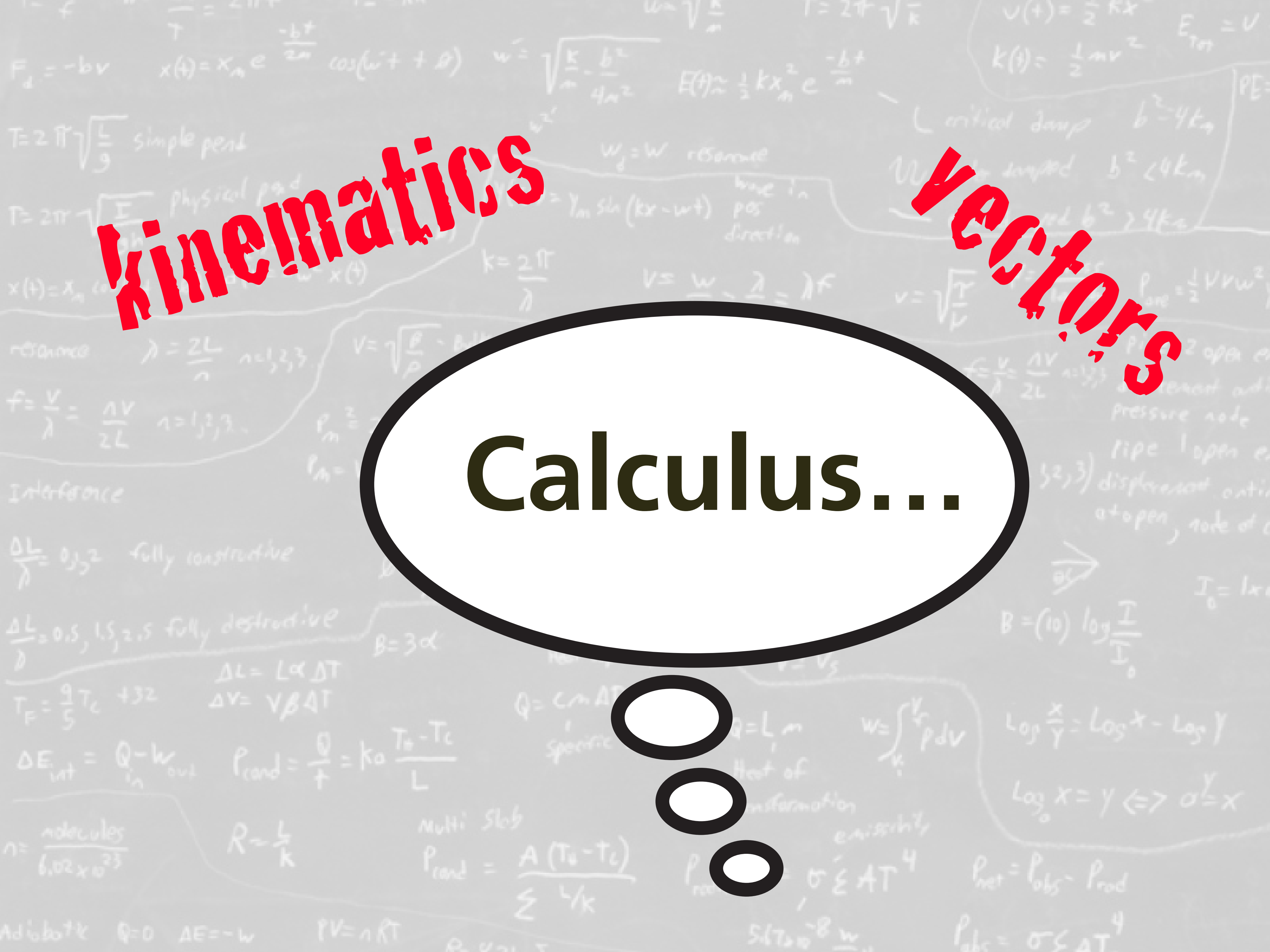
vectors

vectors

Math, not Physics?!

kinematics

vectors


kinematics
vectors
Calculus…

kinematics

vectors

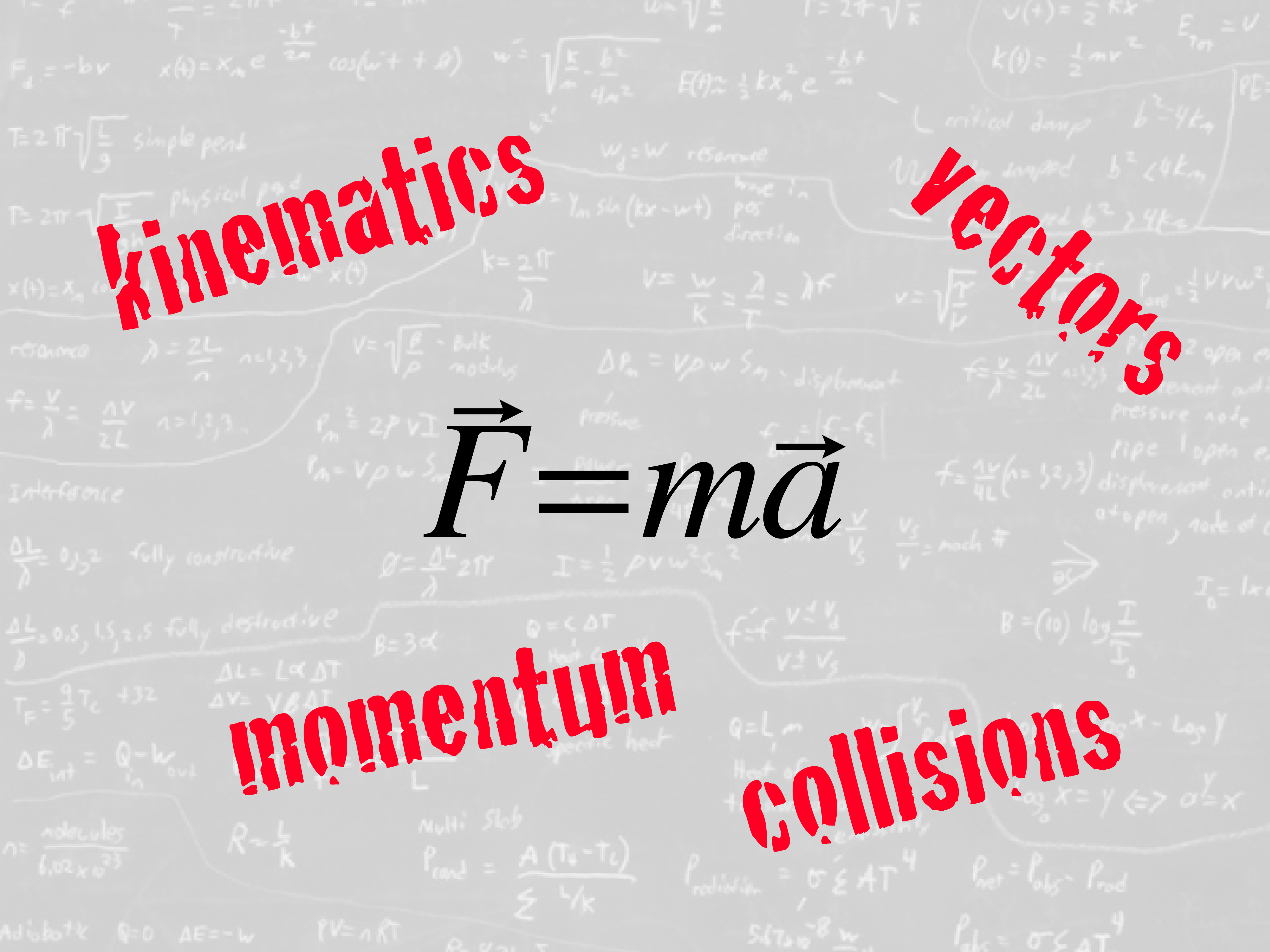
$$\vec{F}=m\vec{a}$$

kinematics

vectors

$$\vec{F}=m\vec{a}$$

momentum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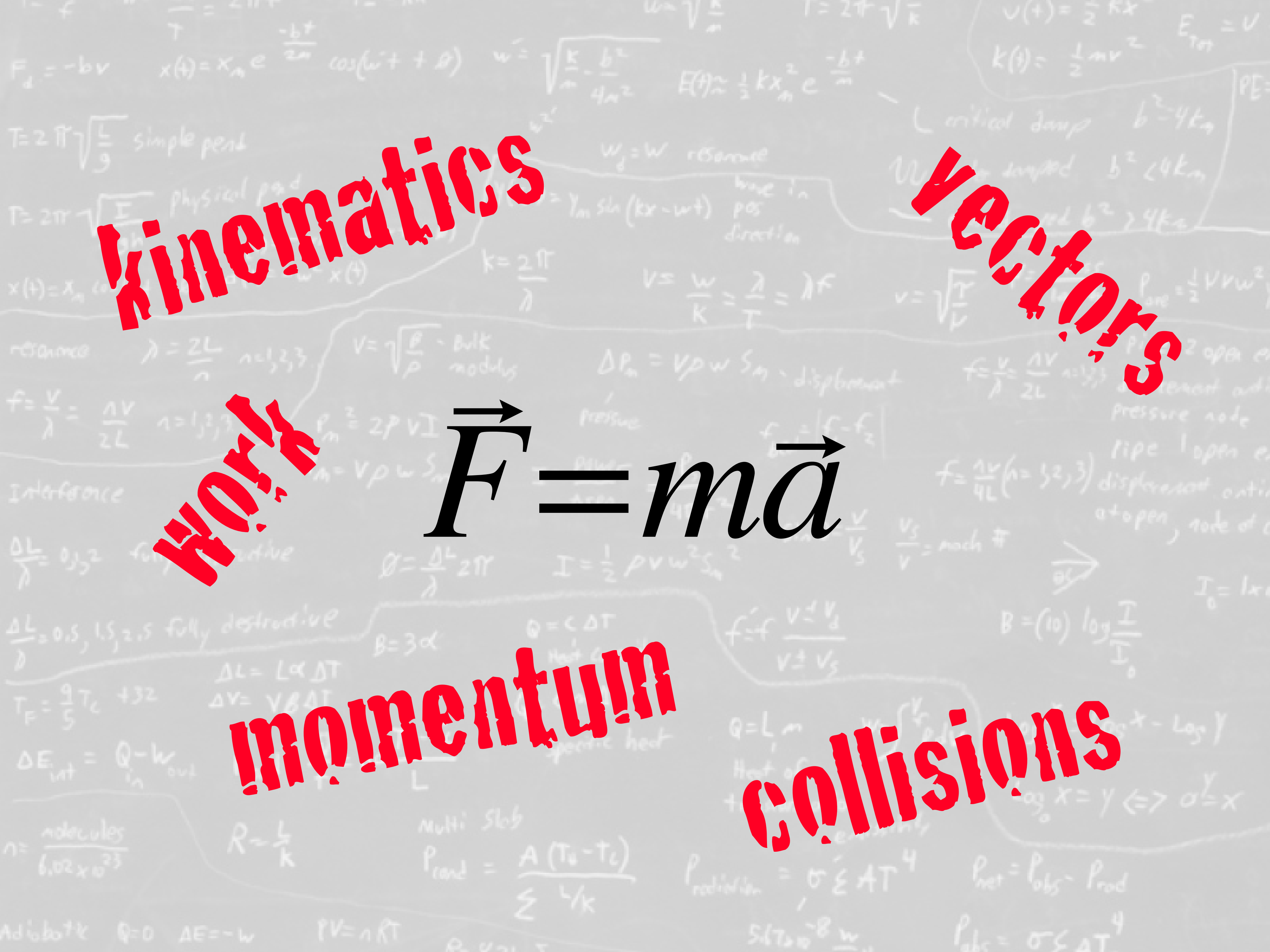
vectors
$\vec{F}=m\vec{a}$
momentum
collisions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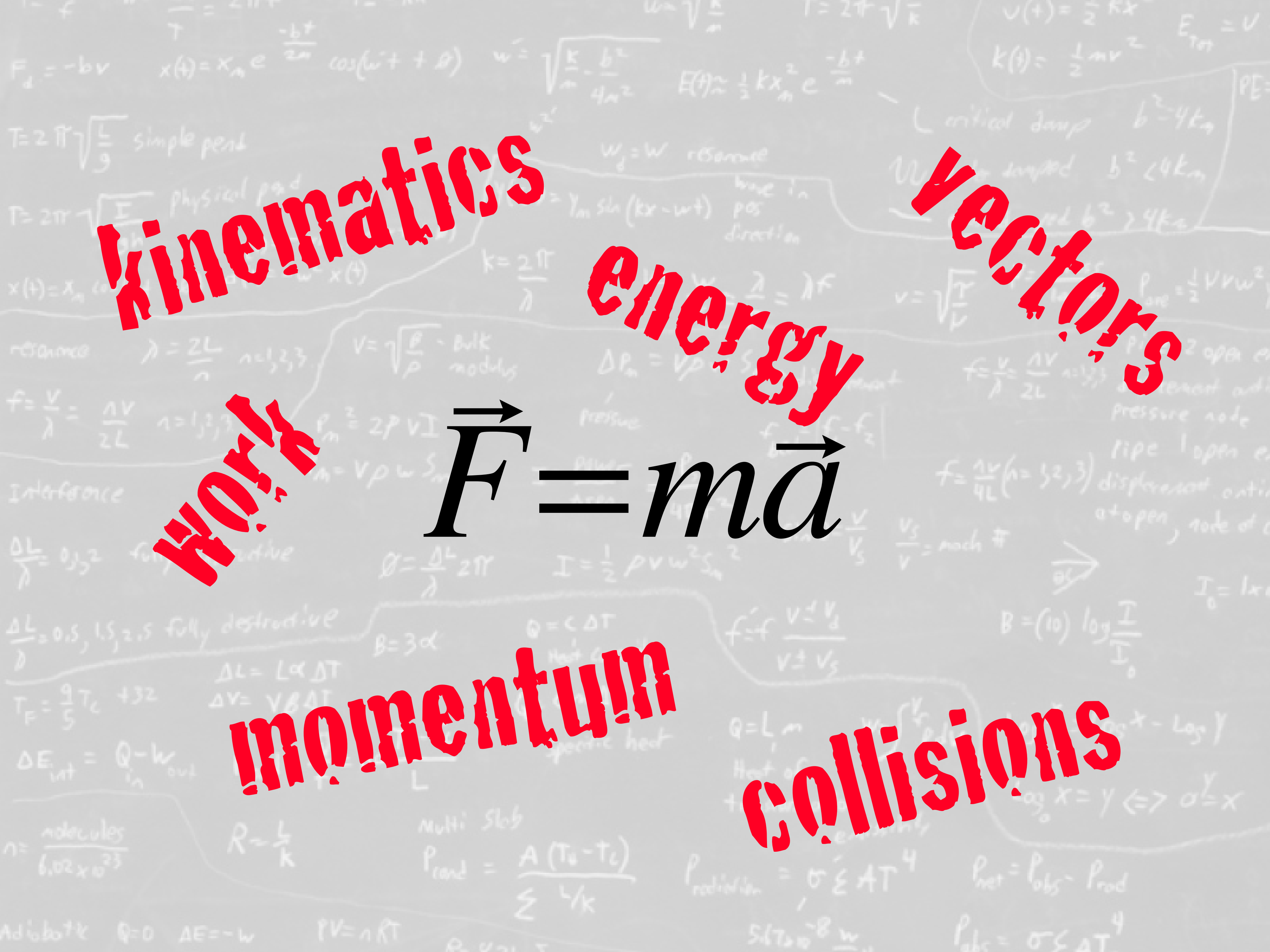
collisions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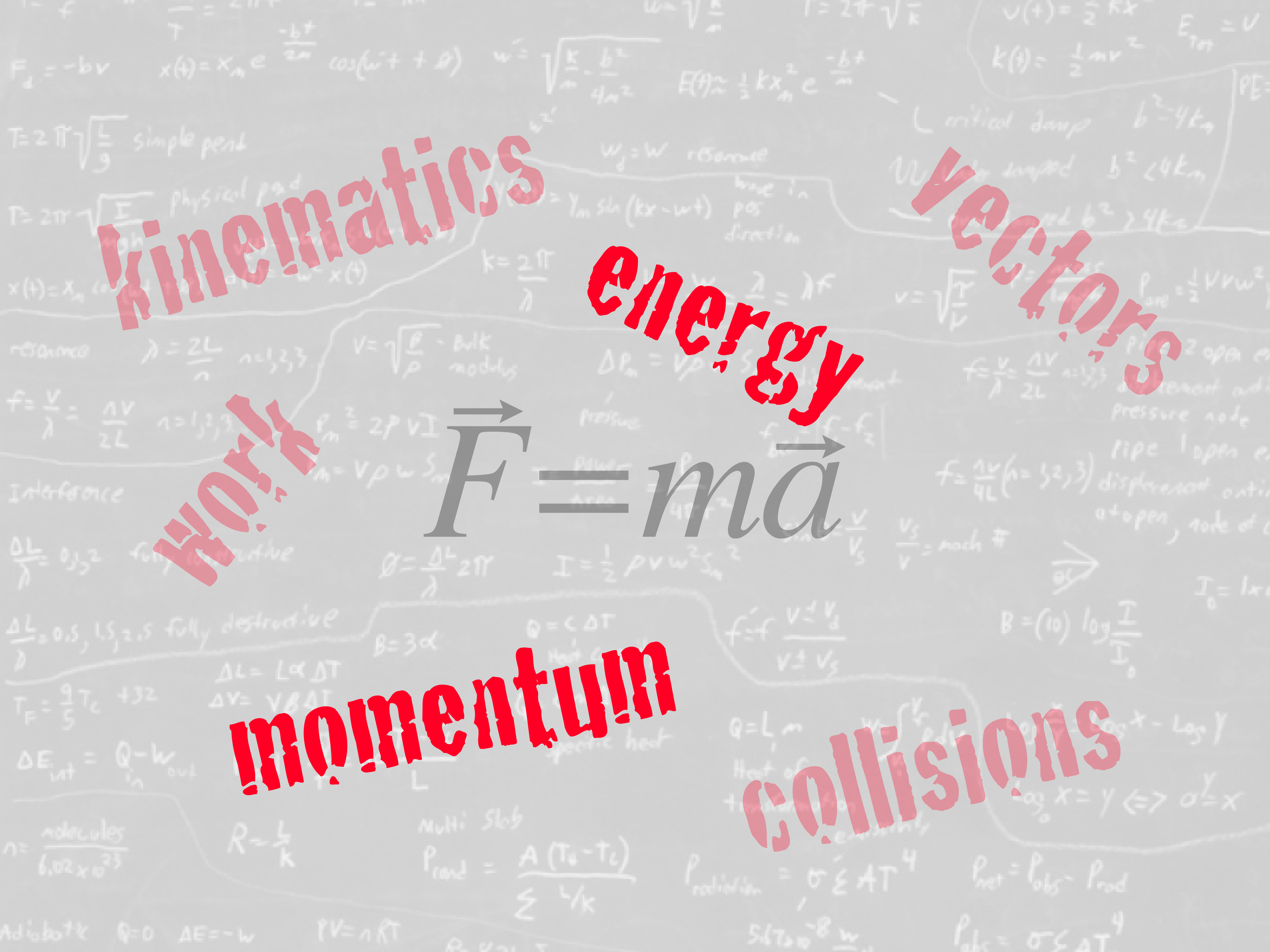
collisions


kinematics
energy
vectors
work
$\vec{F} = m\vec{a}$
momentum
collisions

kinematics

vectors

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work

$$\vec{F} = m\vec{a}$$

momentum

collisions

conservation of energy

$$\vec{F} = m\vec{a}$$

conservation of momentum

kinematics

vectors

work

collisions

conservation of energy

Just algebra!

conservation of momentum

kinematics

vectors

conservation of energy

work

Why not START the easy way?

conservation of momentum

collisions

The historical approach

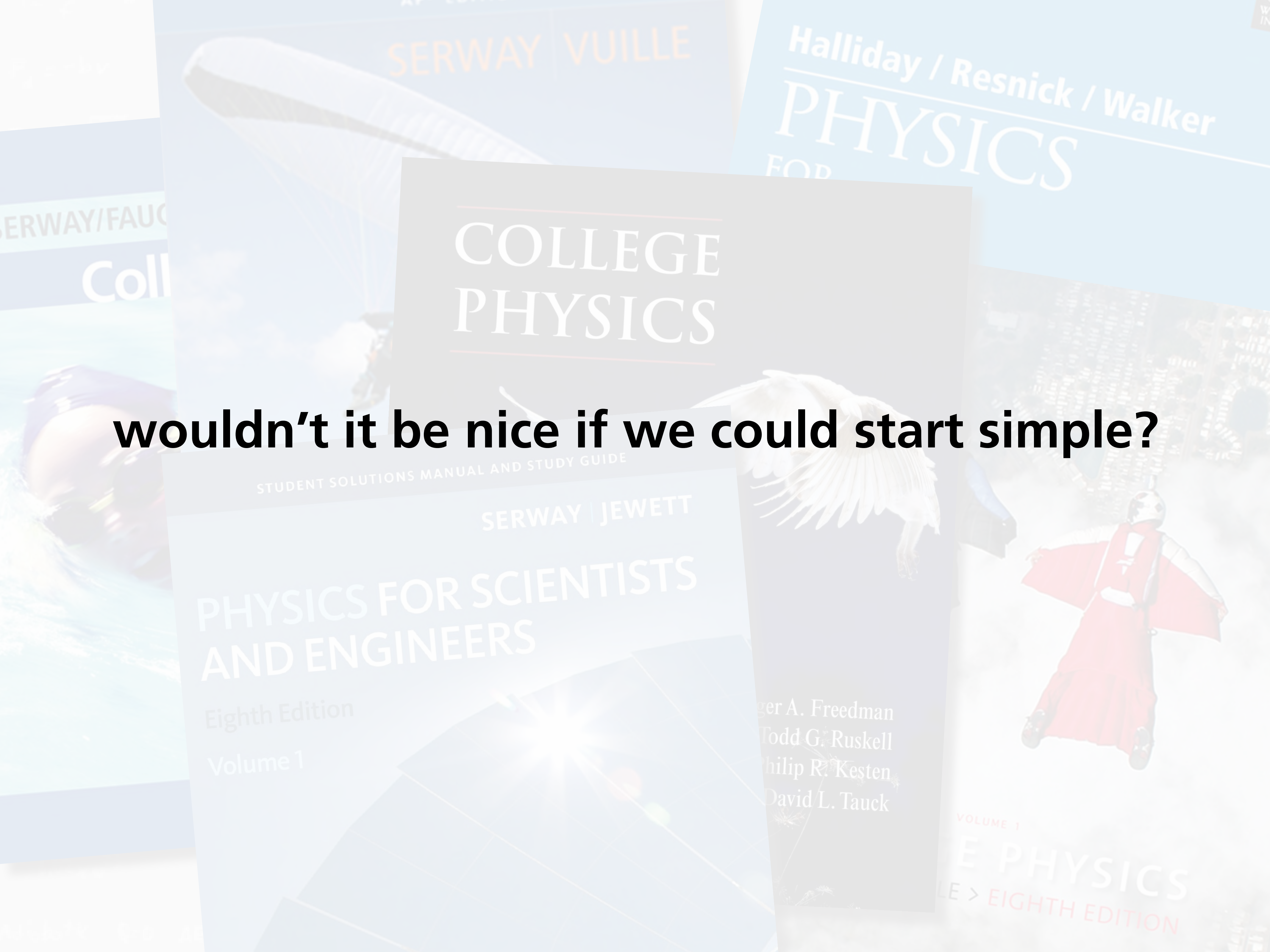
- Newton's laws
- Collisions
- Momentum (and conservation)
- Work and energy
- Conservation of energy

Ernst Mach (1838–1916)

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

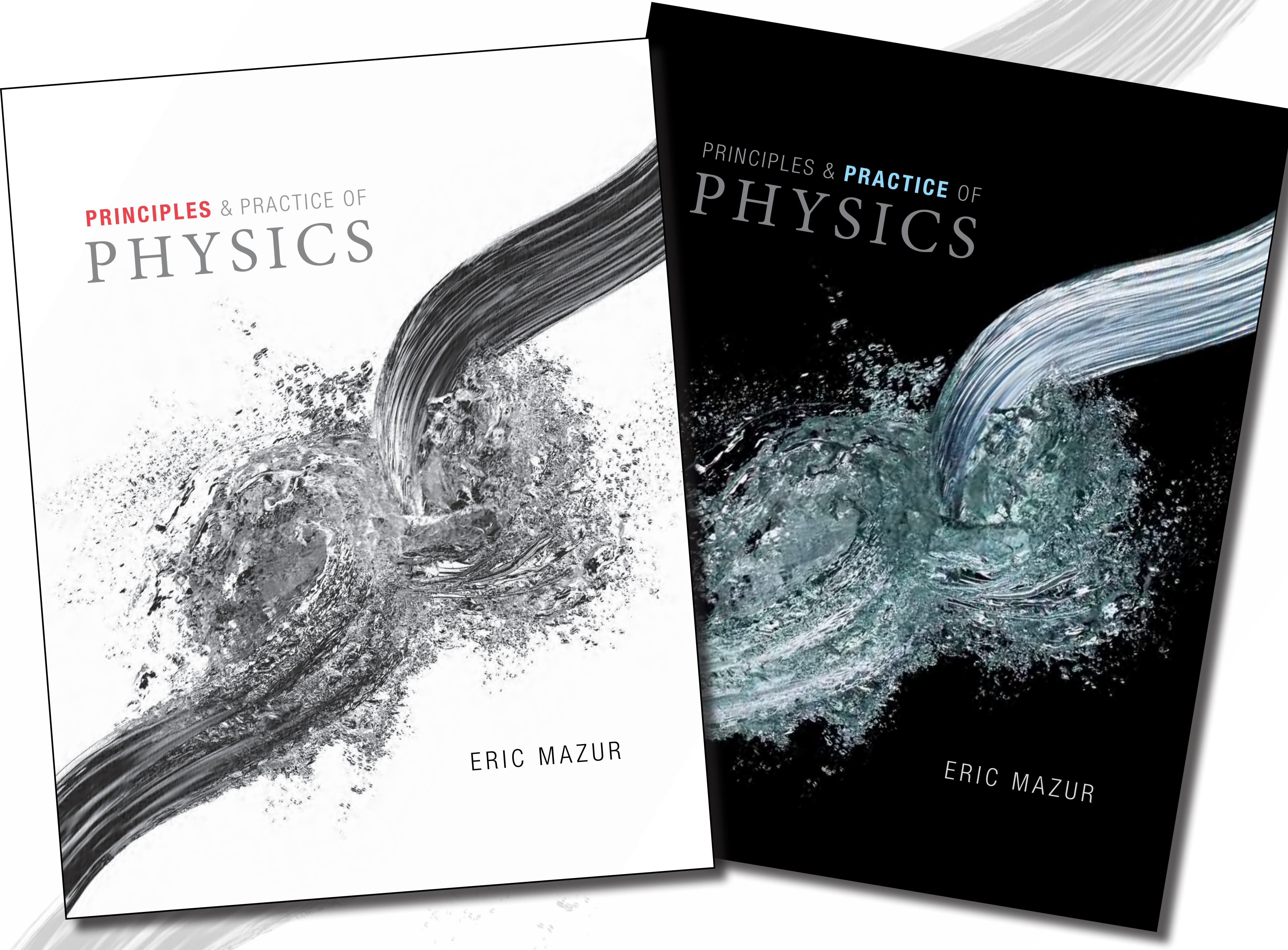
Ernst Mach (1838–1916)

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



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

we can!


PRINCIPLES & PRACTICE OF
PHYSICS
ERIC MAZUR
PRINCIPLES & PRACTICE OF
PHYSICS
ERIC MAZUR

Principles and Practice of Physics

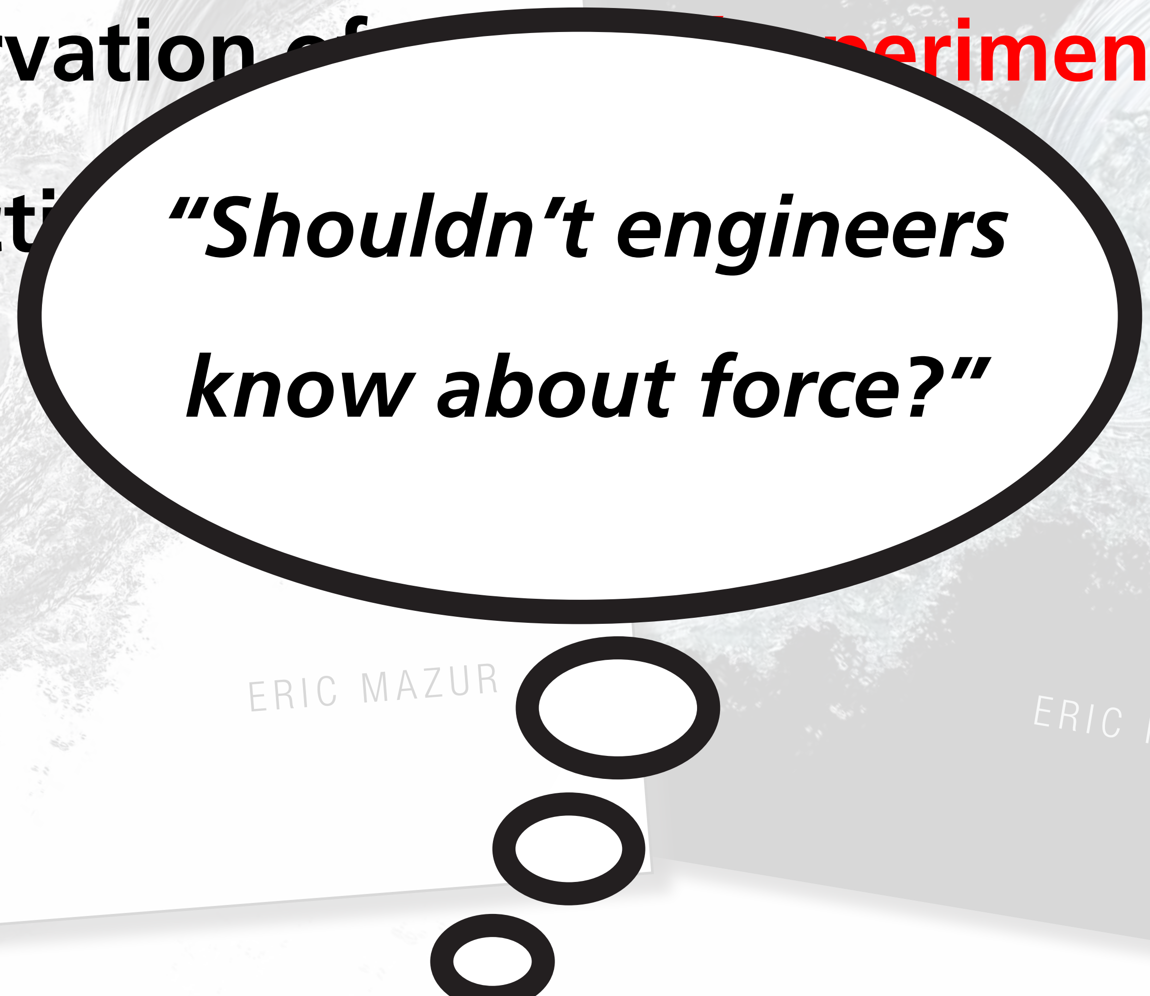
- Conservation of momentum
- Conservation of energy
- Interactions
- Force
- Work

Principles and Practice of Physics

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

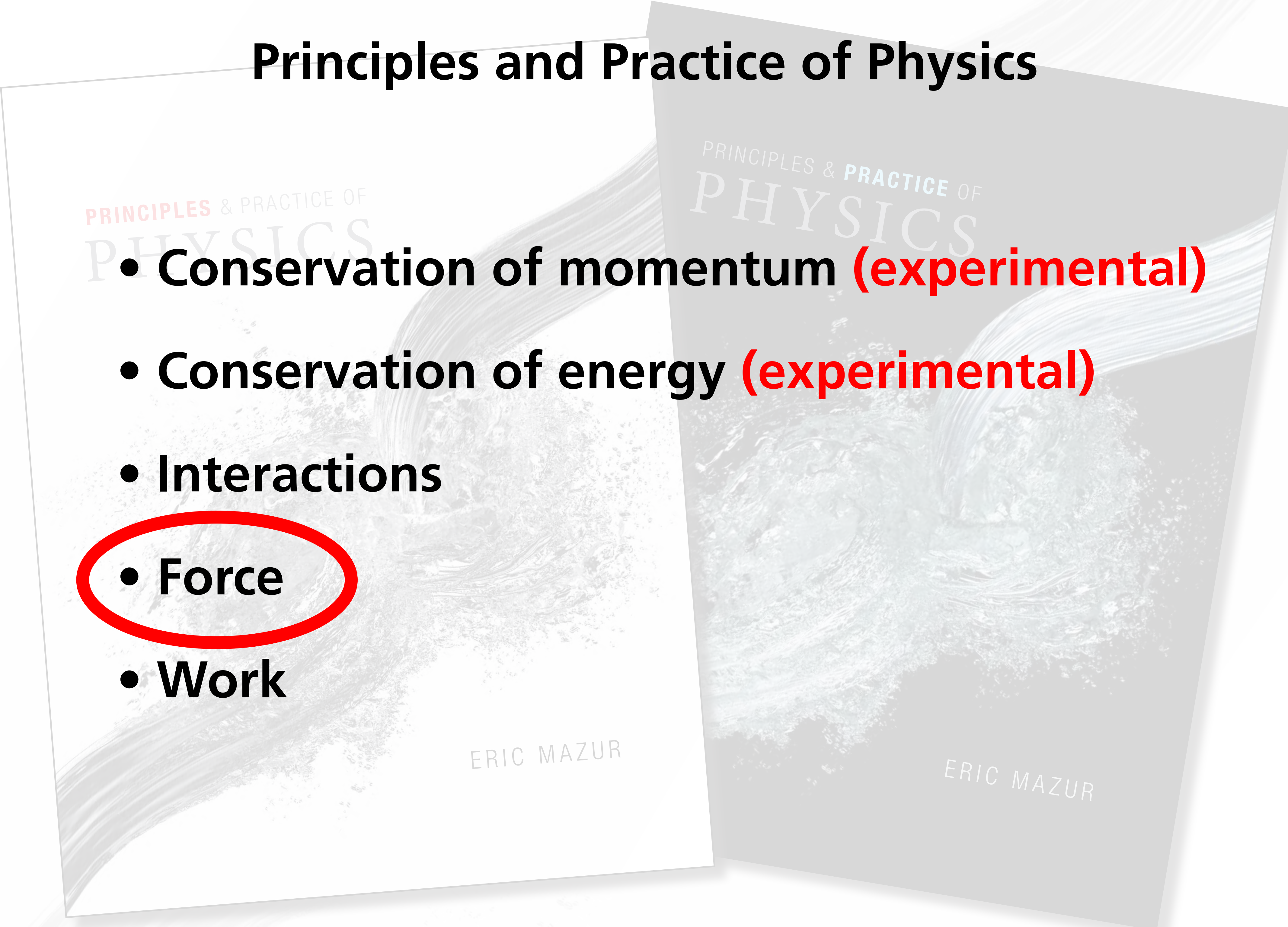
Principles and Practice of Physics

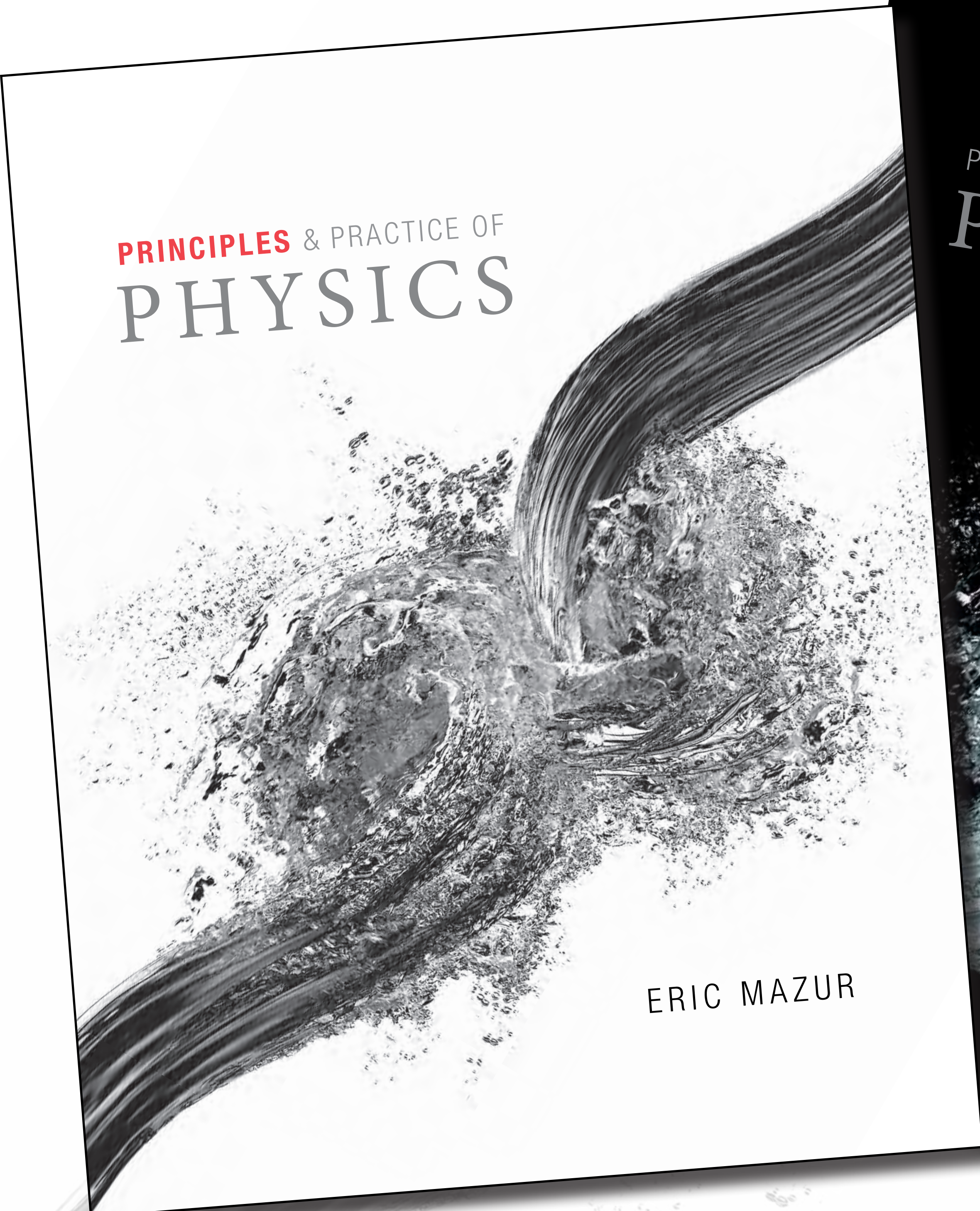
- Conservation of momentum (experimental)
- Conservation of … erimental)
- Interacti…
- Force
- Work



Principles and Practice of Physics

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

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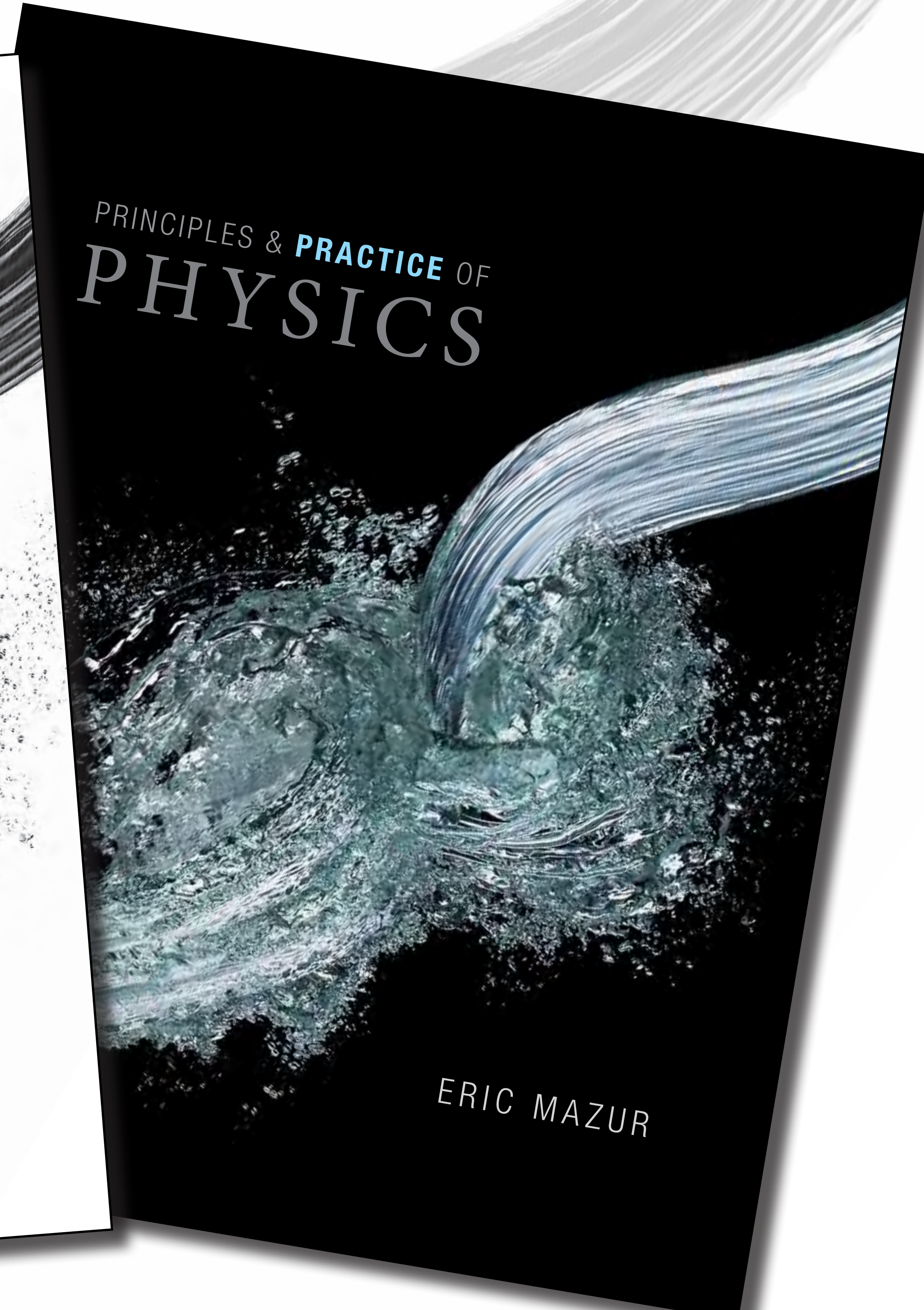
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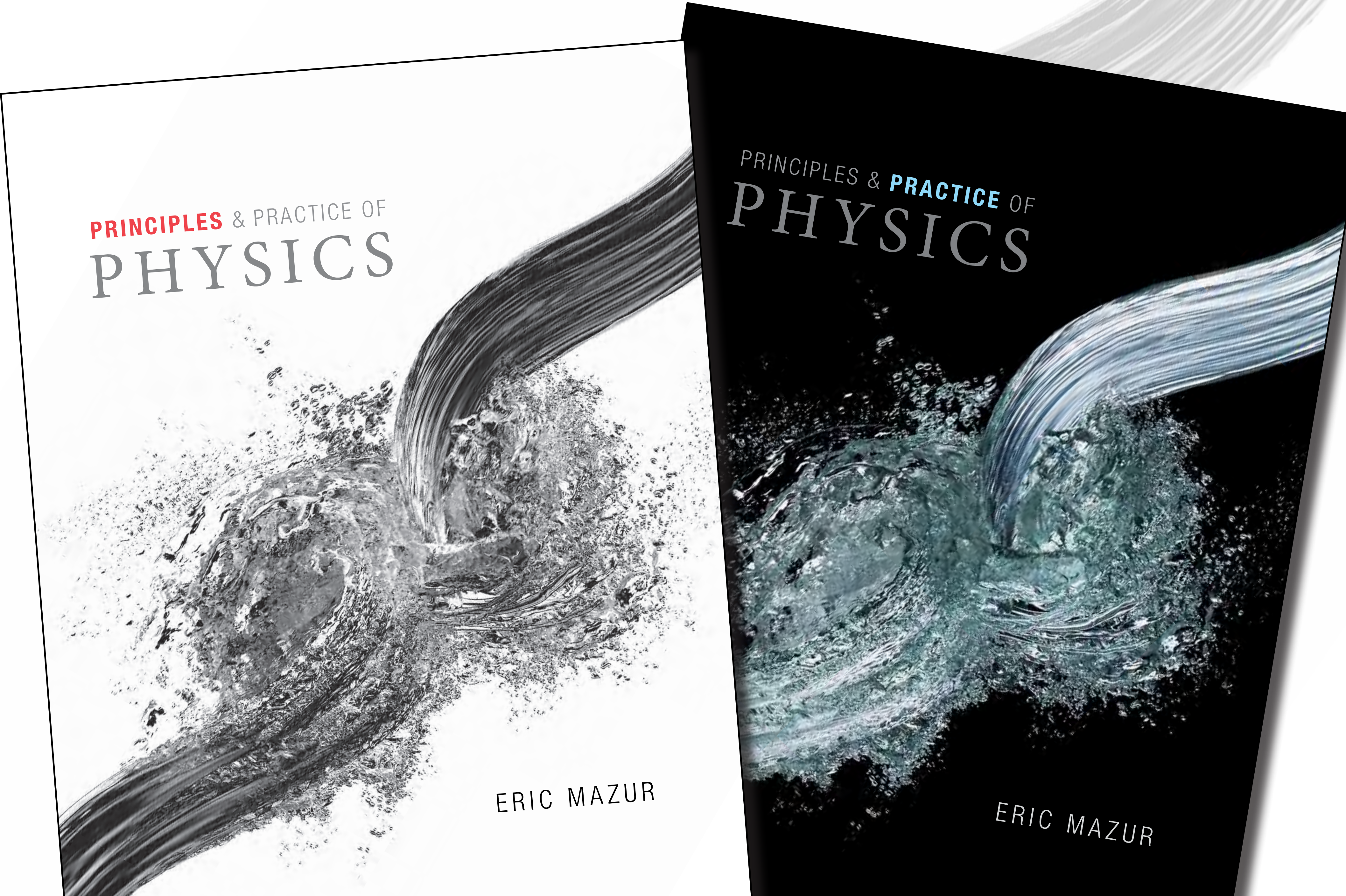

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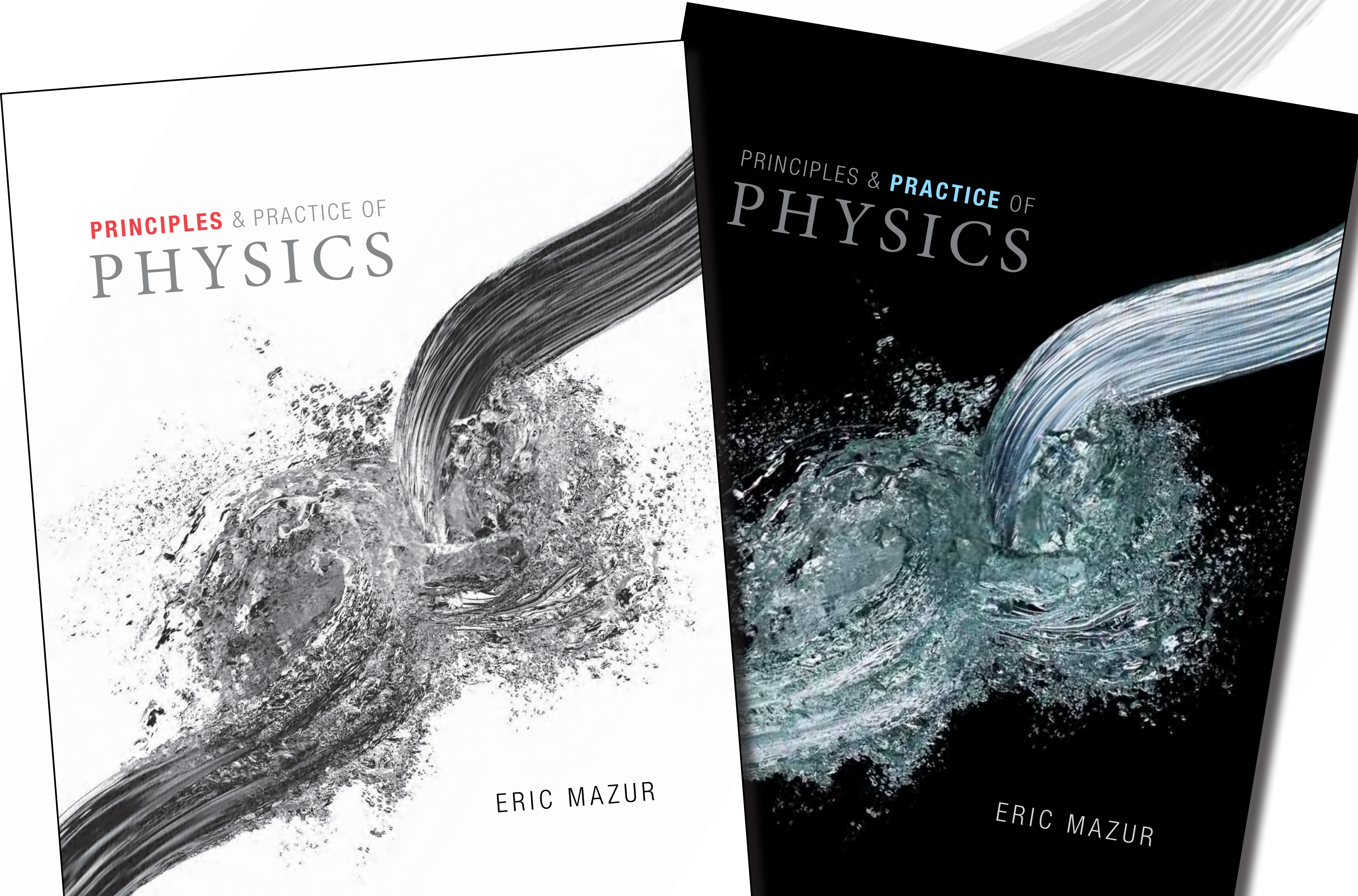
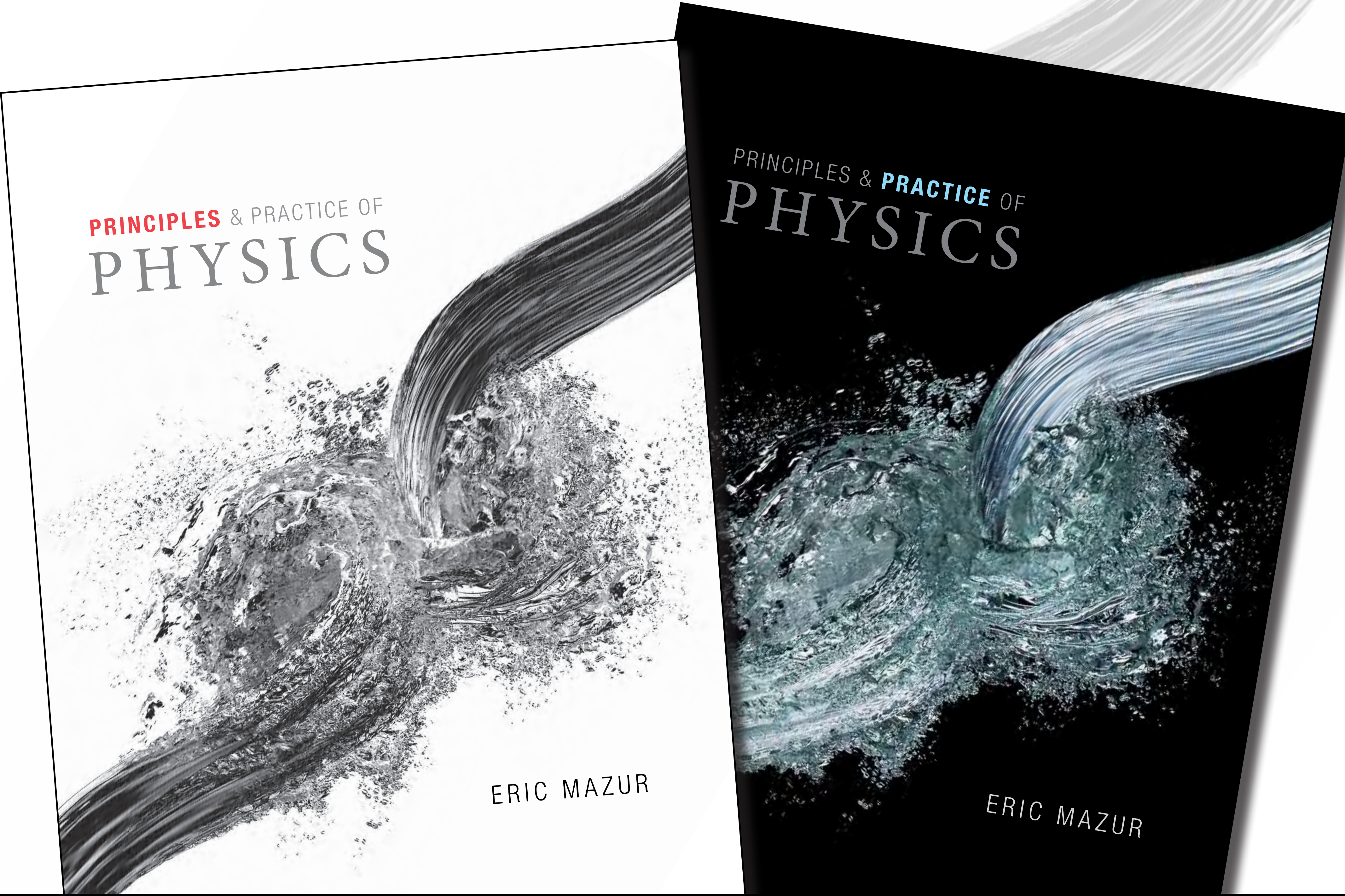


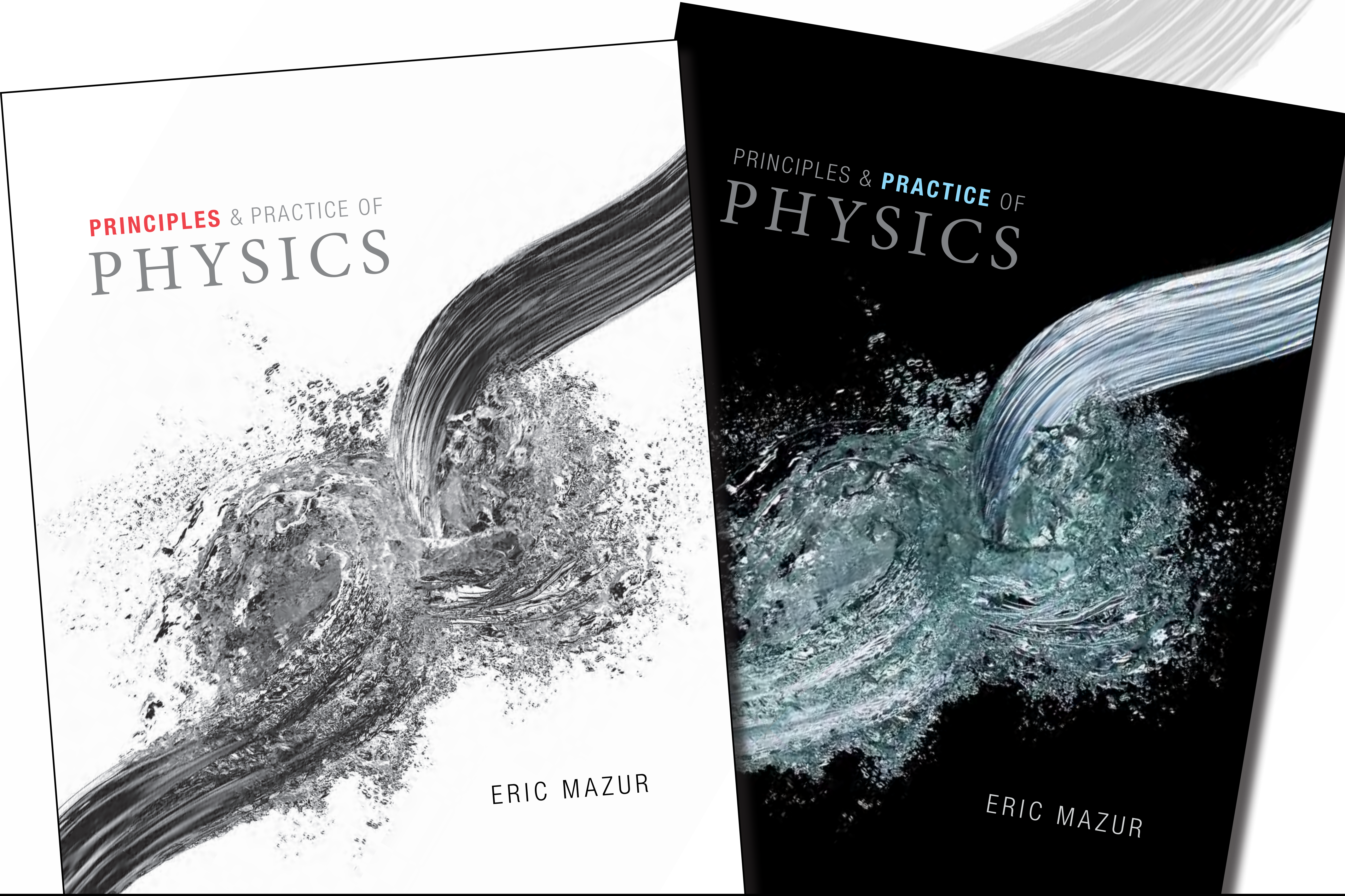
1 architecture 2 content



1 architecture

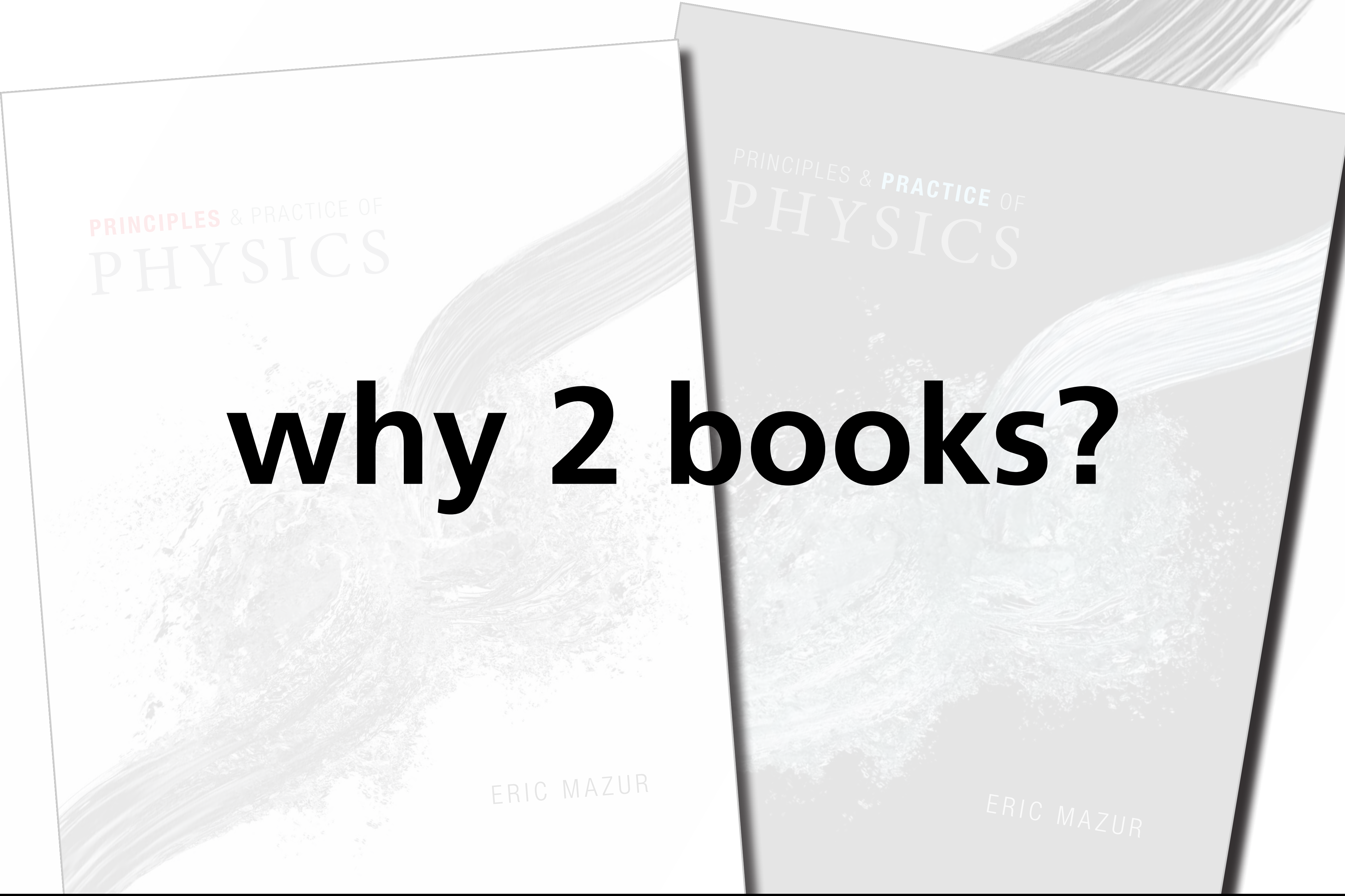
2 content

3 results



1 architecture

why 2 books?



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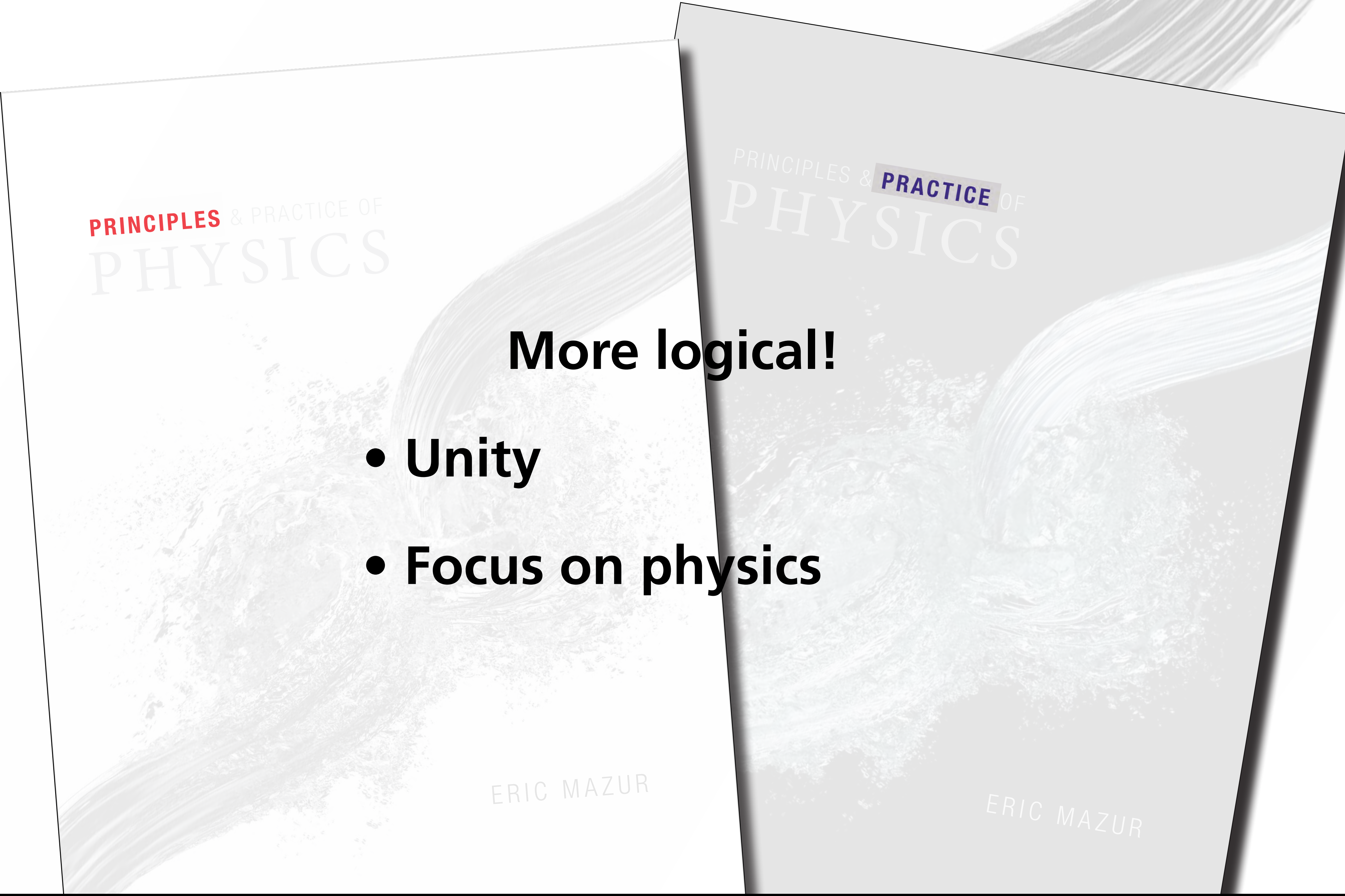


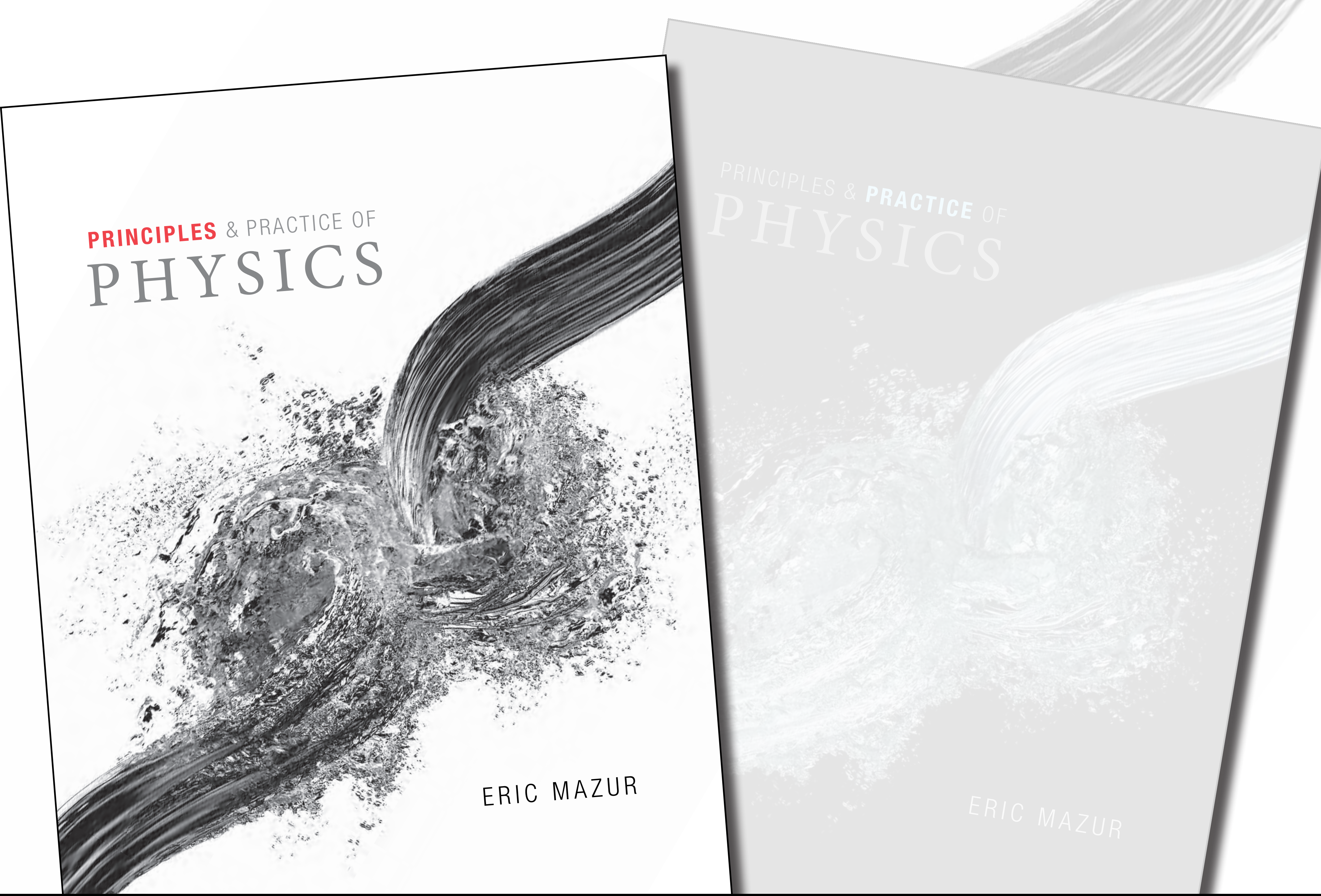
More logical!

- Unity
- Focus on physics

1 architecture

More practical!

- Contexts different
- Lighter



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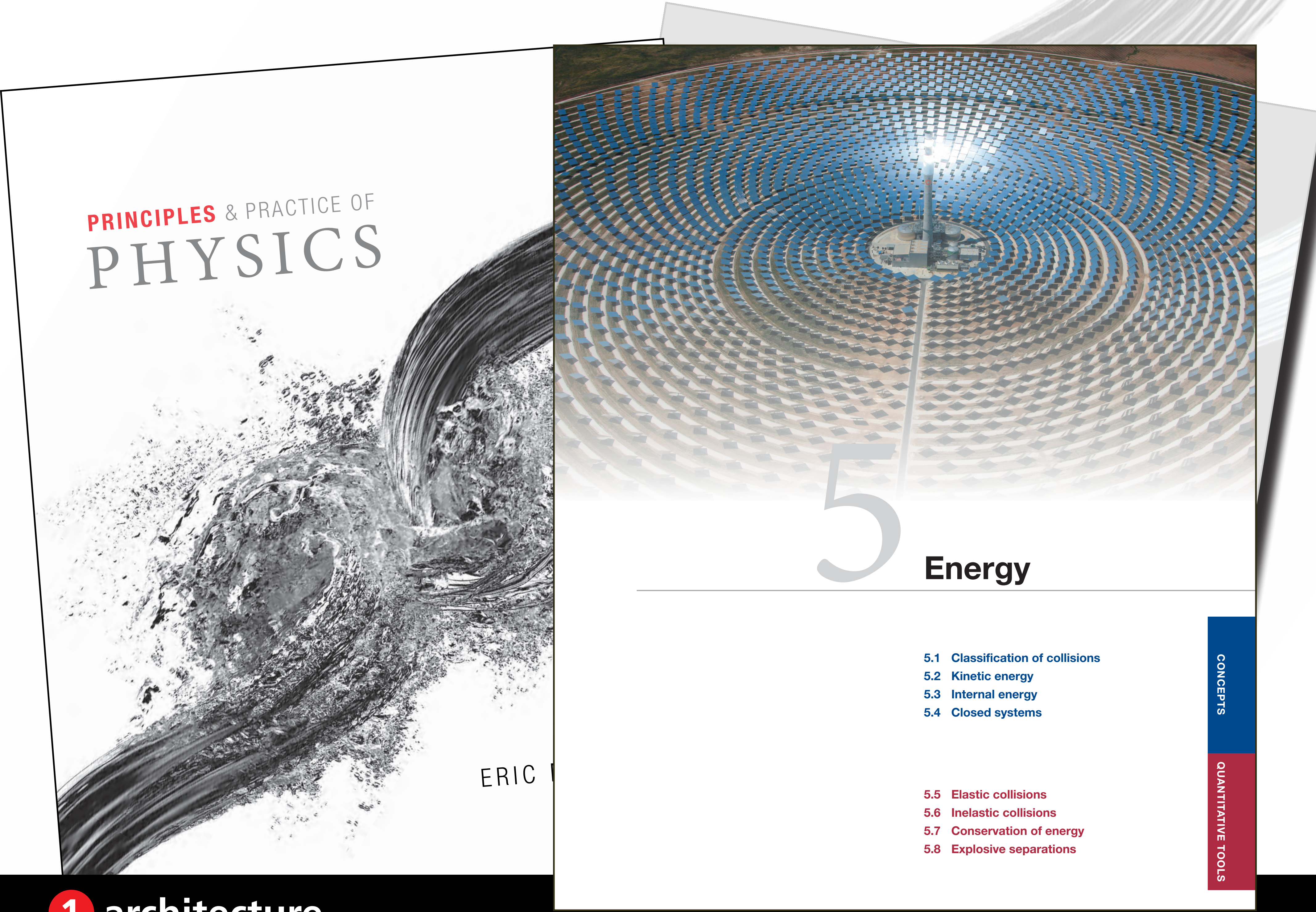

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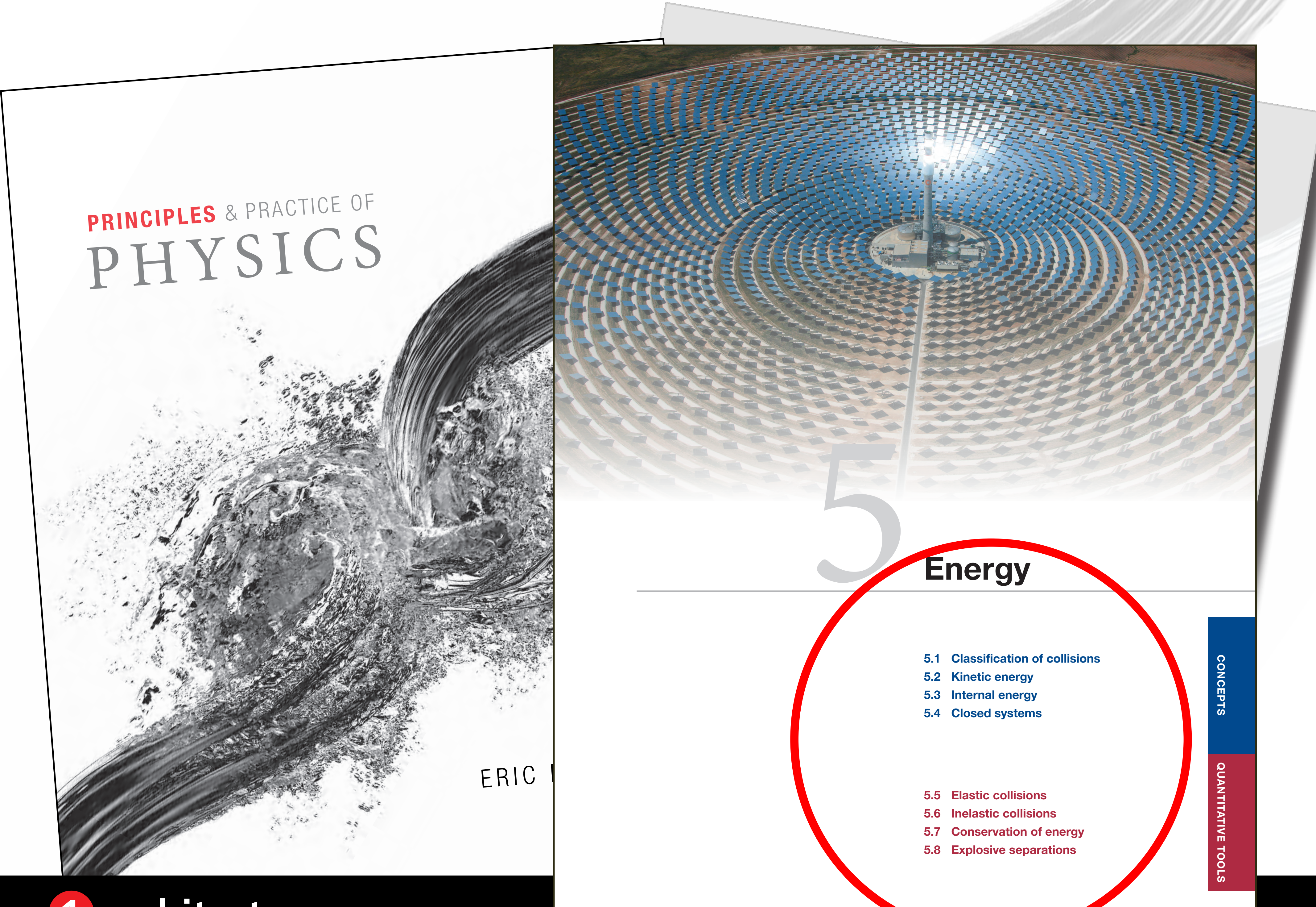

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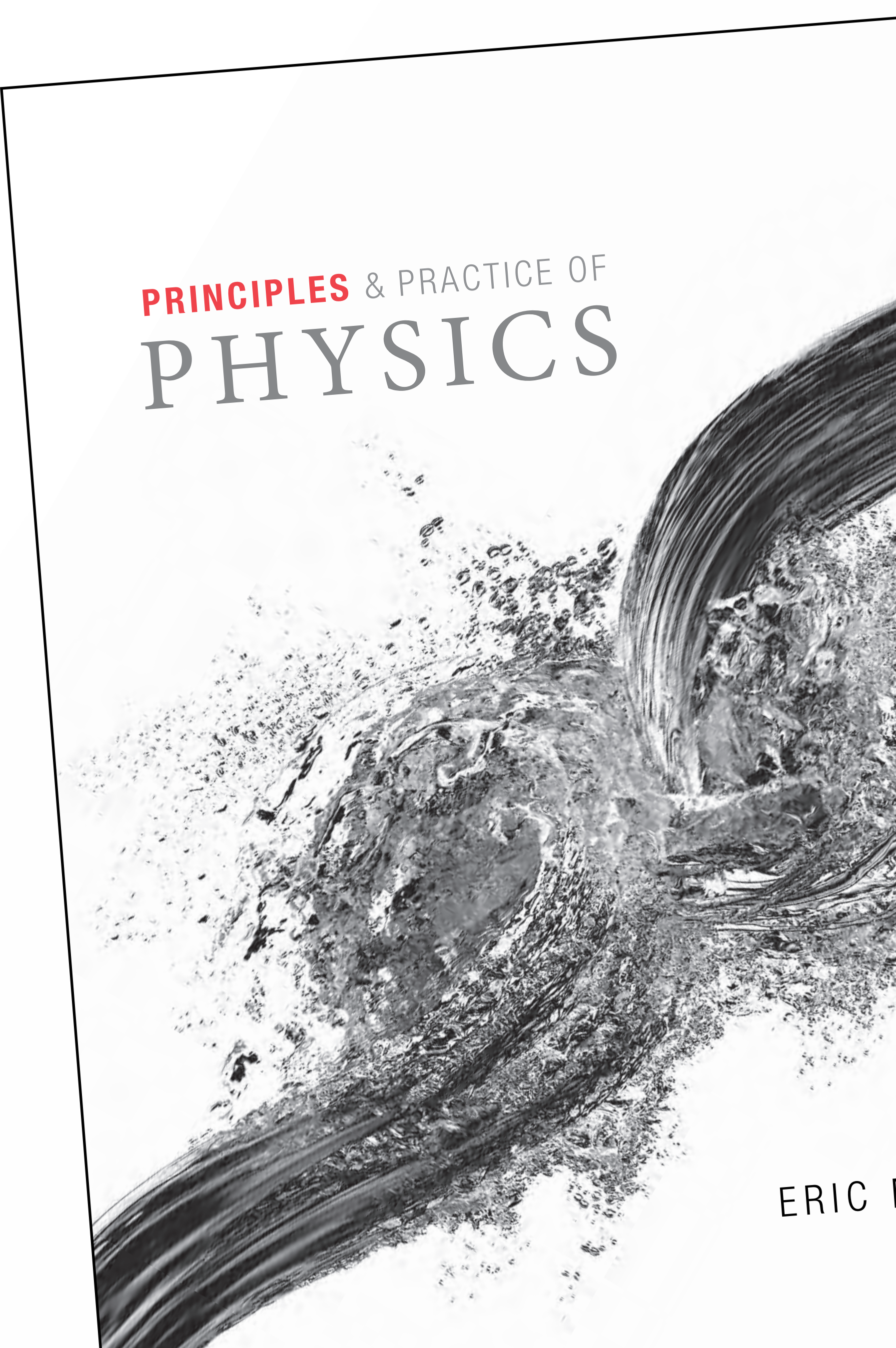

Energy

CONCEPTS

QUANTITATIVE TOOLS

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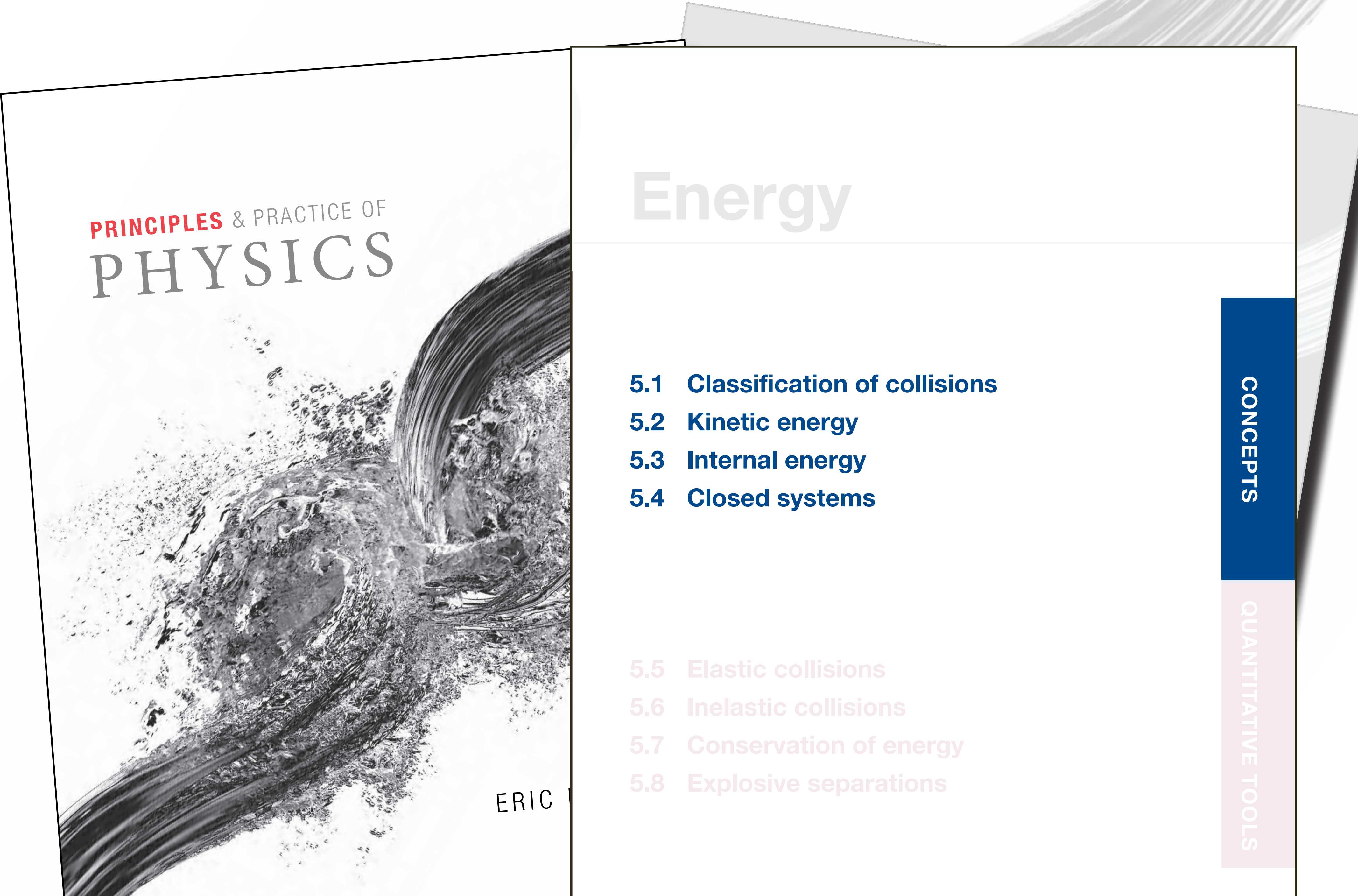

Energy

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

CONCEPTS

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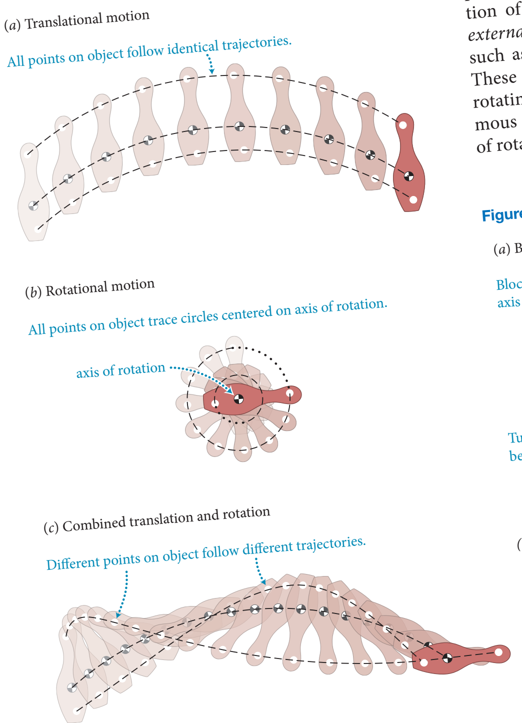
The motion we have been dealing with so far in this text is called **translational motion** (Figure 11.1*a*). This type of motion involves no change in an object's orientation; in other words, all the particles in the object move along identical parallel trajectories. During **rotational motion,** which 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 11.1*b*). Generally, the motion of rigid objects is a combination of these two types of motion (Figure 11.1*c*), 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 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.

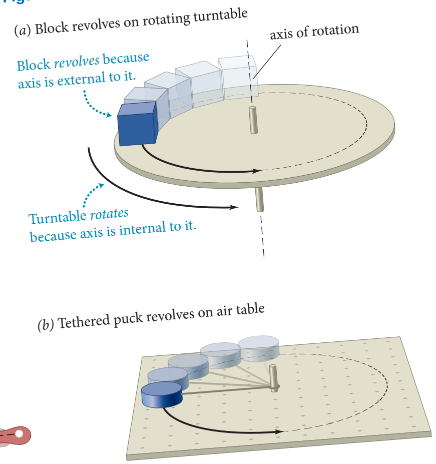
Figure 11.1 Translational and rotational motion of a rigid object.



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 11.2*a*, 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.



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QUANTITATIVE TOOLS

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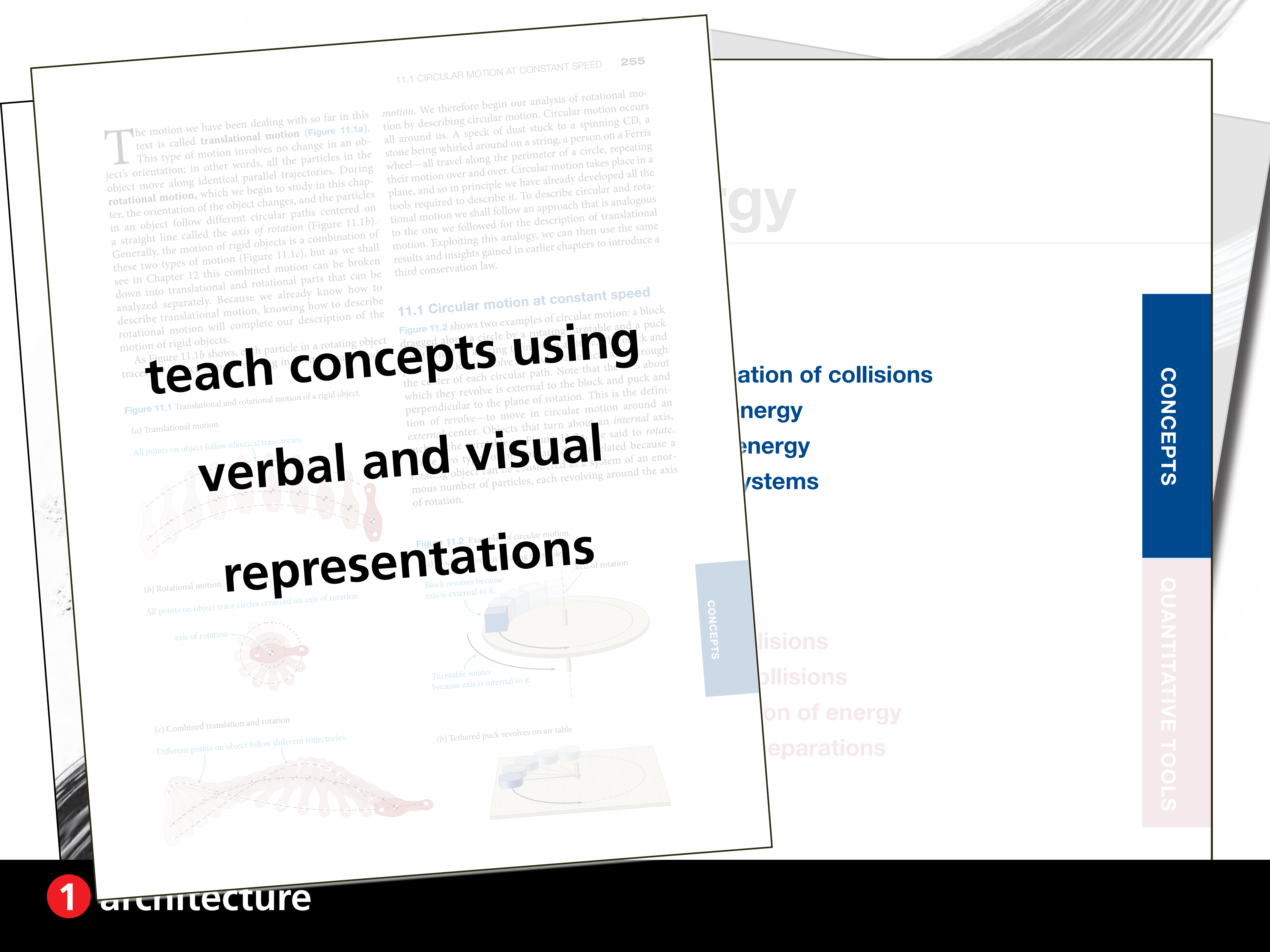

teach concepts using
verbal and visual
representations
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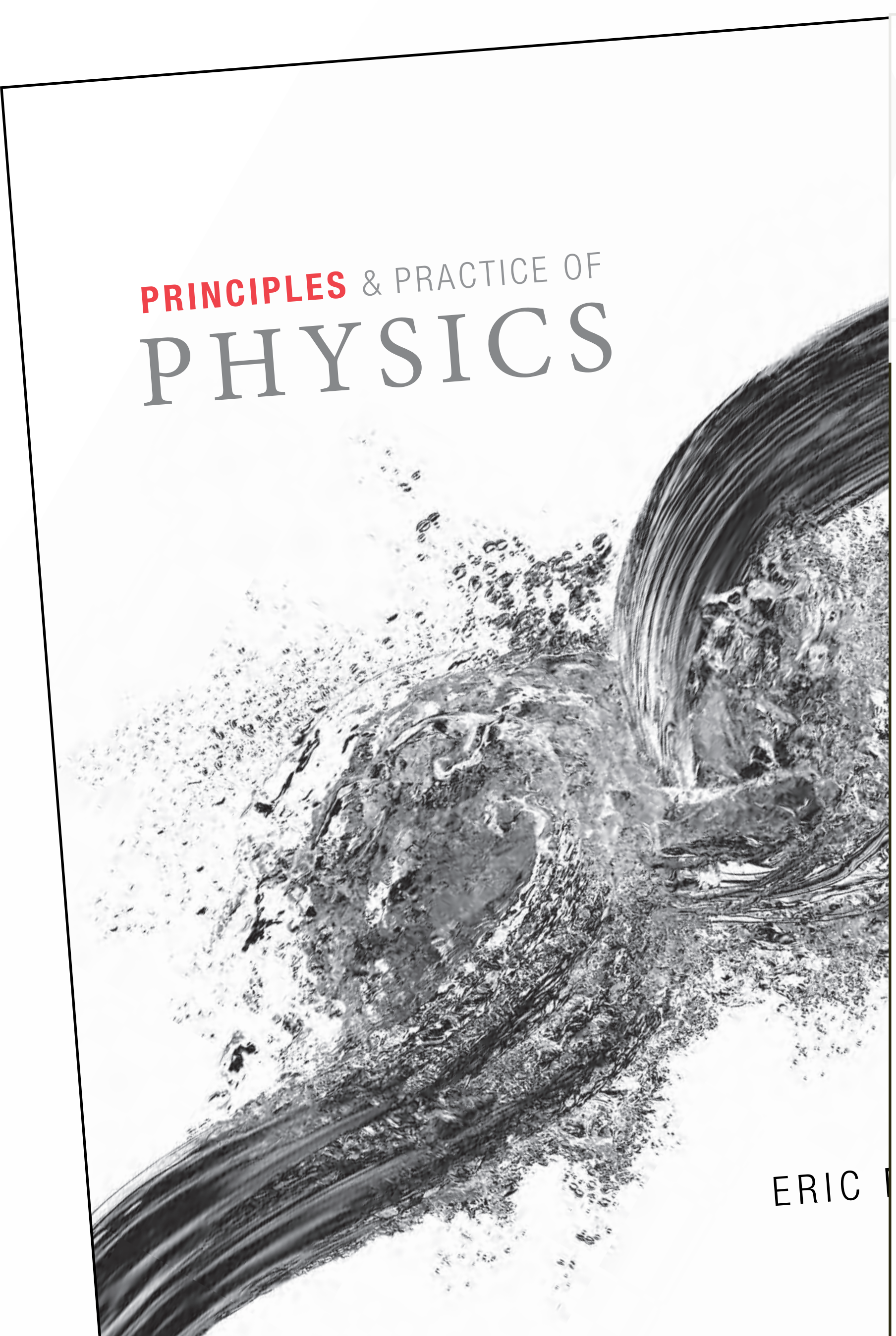

Energy

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

CONCEPTS

QUANTITATIVE TOOLS

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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 6.13*b*).* 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

$$t_{Ae} = t_{Be}. \tag{6.1}$$

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

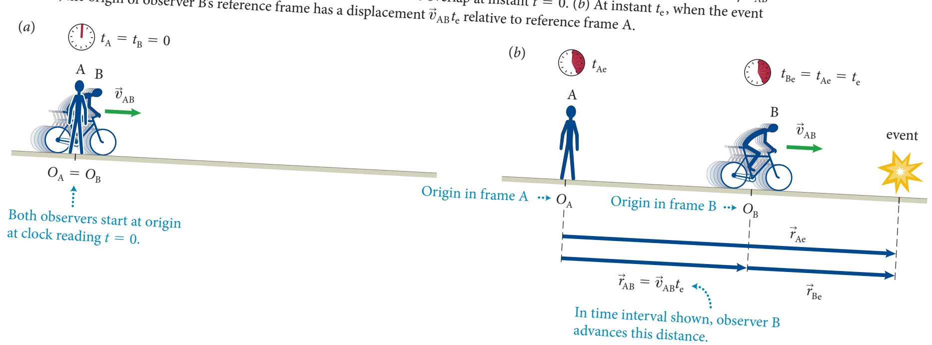
$$t_A = t_B = t. \tag{6.2}$$

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 $\vec{v}_{AB}$. Therefore

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

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 A's measurement of the position at which the event occurs.

QUANTITATIVE TOOLS

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CONCEPTS

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QUANTITATIVE TOOLS

1 architecture

build on conceptual underpinnings to effectively teach quantitative tools

1 architecture

(*b*) From Figure 10.18 I see that $\tan\theta = |F^c_{sp\,x}|/|F^c_{sp\,y}|$. For $\theta < 45°$, $\tan\theta < 1$, and so $|F^c_{sp\,x}| < |F^c_{sp\,y}|$. Because $|F^c_{sp\,y}| = F^G_{Ep}$ and $|F^c_{sp\,x}| = F^c_{rp}$, I find that for $\theta < 45°$, $F^c_{rp} < F^G_{Ep}$. When $\theta > 45°$, $\tan\theta > 1$, and so $|F^c_{sp\,x}| > |F^c_{sp\,y}|$ and $F^c_{rp} > F^G_{Ep}$. ✔

(*c*) $|\vec{F}^c_{sp\,y}| = F^G_{Ep}$ and $F^c_{sp} = \sqrt{(F^c_{sp\,x})^2 + (F^c_{sp\,y})^2}$. Therefore, F^c_{sp} must always be larger than F^G_{Ep} when $\theta \neq 0$. ✔

❹ **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 $\vec{F}^c_{rp}$ and $\vec{F}^G_{Ep}$ on your friend make the same angle with the force $\vec{F}^c_{sp}$, and so $\vec{F}^c_{rp}$ and $\vec{F}^G_{Ep}$ 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°, $\vec{F}^c_{rp}$ is larger than $\vec{F}^G_{Ep}$. In part *c*, because the vertical component of the force $\vec{F}^c_{sp}$ exerted by the seat on your friend always has to be equal to the force of gravity, adding a horizontal component makes $\vec{F}^c_{sp}$ larger than $\vec{F}^G_{Ep}$, 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 this instant.

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

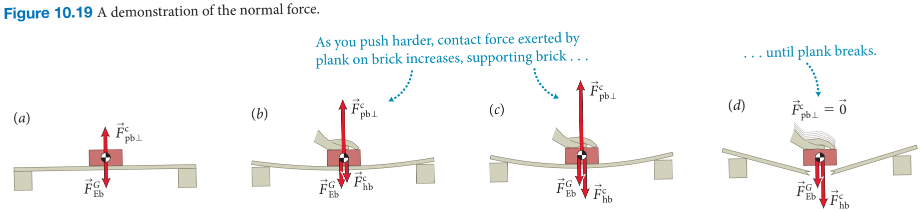
Even though the normal and tangential components of the contact force exerted by the floor on the cabinet belong to the same interaction, they behave differently and are usually treated as two separate forces: the normal component being called the **normal force** and the tangential component being called 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 10.19*a*). Because the brick is at rest, the normal force $\vec{F}^c_{pb\perp}$ 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 $\vec{F}^c_{hb}$. 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 10.19*b*). As you push down harder, the plank bends more, and the normal force continues to increase (Figure 10.19*c*) until you exceed the plank's capacity to provide support and it snaps, at which point the normal force suddenly disappears (Figure 10.19*d*). 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 10.19*a*, 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.**

CONCEPTS

Figure 10.19 A demonstration of the normal force.



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CONCEPTS

collisions
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QUANTITATIVE TOOLS

1 architecture

(*b*) From Figure 10.18 I see that $\tan\theta = |F^c_{sp\,x}|/|F^c_{sp\,y}|$. For $\theta < 45°$, $\tan\theta < 1$, and so $|F^c_{sp\,x}| < |F^c_{sp\,y}|$. Because $|F^c_{sp\,y}| = F^G_{Ep}$ and $|F^c_{sp\,x}| = F^c_{rp}$, I find that for $\theta < 45°$, $F^c_{rp} < F^G_{Ep}$. When $\theta > 45°$, $\tan\theta > 1$, and so $|F^c_{sp\,x}| > |F^c_{sp\,y}|$ and $F^c_{rp} > F^G_{Ep}$. ✔

(*c*) $|\vec{F}^c_{sp\,y}| = F^G_{Ep}$ and $F^c_{sp} = \sqrt{(F^c_{sp\,x})^2 + (F^c_{sp\,y})^2}$. Therefore, F^c_{sp} must always be larger than F^G_{Ep} 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 $\vec{F}^c_{rp}$ and $\vec{F}^G_{Ep}$ on your friend make the same angle with the force $\vec{F}^c_{sp}$, and so $\vec{F}^c_{rp}$ and $\vec{F}^G_{Ep}$ 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°, $\vec{F}^c_{rp}$ is larger than $\vec{F}^G_{Ep}$. In part *c*, because the vertical component of the force $\vec{F}^c_{sp}$ exerted by the seat on your friend always has to be equal to the force of gravity, adding a horizontal component makes $\vec{F}^c_{sp}$ larger than $\vec{F}^G_{Ep}$, 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 this instant.

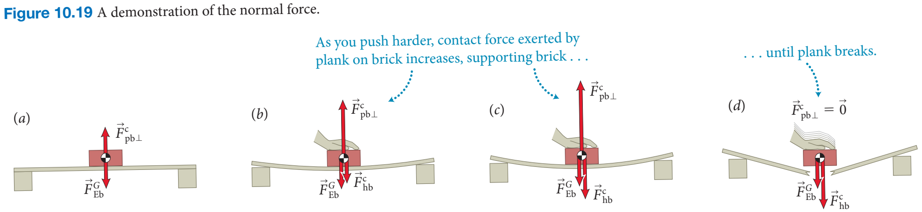
Don't skip Checkpoint 10.5! It will be harder to understand the rest of this section if you haven't thought about these situations.

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 10.19*a*). Because the brick is at rest, the normal force $\vec{F}^c_{pb\perp}$ 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 $\vec{F}^c_{hb}$. 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 10.19*b*). As you push down harder, the plank bends more, and the normal force continues to increase (Figure 10.19*c*) until you exceed the plank's capacity to provide support and it snaps, at which point the normal force suddenly disappears (Figure 10.19*d*). 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 10.19*a*, 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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10.4 Friction

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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 this instant.

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

Figure 10.19 A demonstration of the normal force.

As you push harder, con
plank on brick increases

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As you push harder, con
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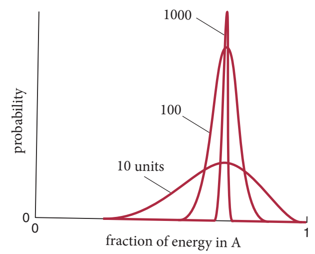

Figure 19.14 Probability of finding a given fraction of the system's energy in compartment A of the box in Figure 19.13. As the number of energy units increases from 10 to 1000, the probability distribution becomes narrower but remains centered about the mean energy.

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 (2.00×10^7; 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 $E_A = 7$?

❶ **GETTING STARTED** Because all basic states are equally likely, the probability of finding the system in macrostate E_A is equal to the fraction Ω/Ω_{tot}, where Ω is the number of basic states of the system associated with the macrostate E_A and Ω_{tot} is the total number of basic states associated with all macrostates (2.00×10^7; Table 19.2).

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

❸ **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 $E_A = 7$, $\Omega = 4.34 \times 10^6$. So the probability of this macrostate occurring is $(4.34 \times 10^6)/(2.00 \times 10^7) = 2.17 \times 10^{-1}$. ✔

❹ **EVALUATE RESULT** My result shows that the macrostate $E_A = 7$ is more than 150 times more probable than the macrostate $E_A = 1$. 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 m^3 containing air at atmospheric pressure and room temperature, there are on the order of 10^{25} particles and 10^{20} energy units per particle, and so the number of basic states becomes unimaginably large—on the order of ten raised to the power 10^{21}! 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_A increases, the number of basic states Ω_A increases. As E_A increases, however, E_B decreases and so Ω_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 $E_A = 1$ the number of basic states for the system (2.80×10^4) 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

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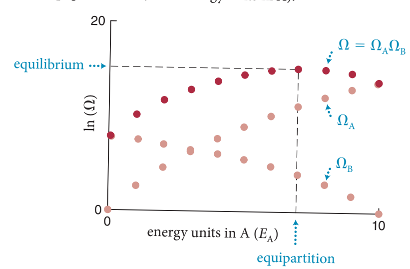
Figure 19.15 Natural logarithm of the number of basic states for compartment A, for compartment B, and for the two compartments in Figure 19.13 combined. The number of basic states is maximal when the energy is equipartitioned (seven energy units in A).



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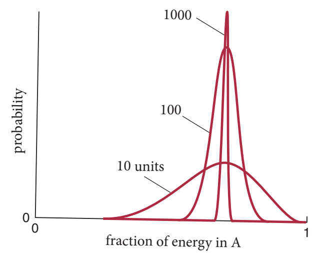

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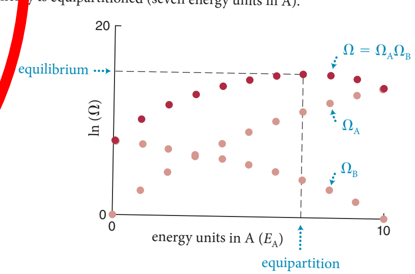

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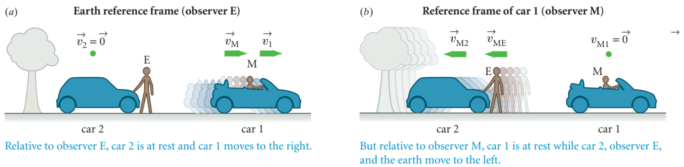
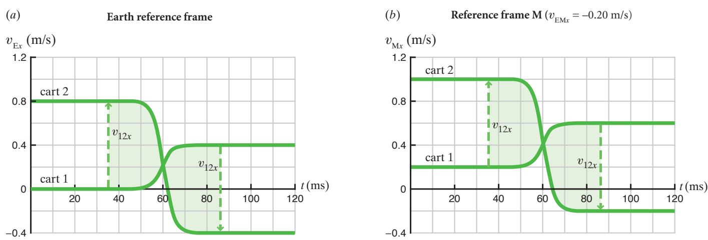
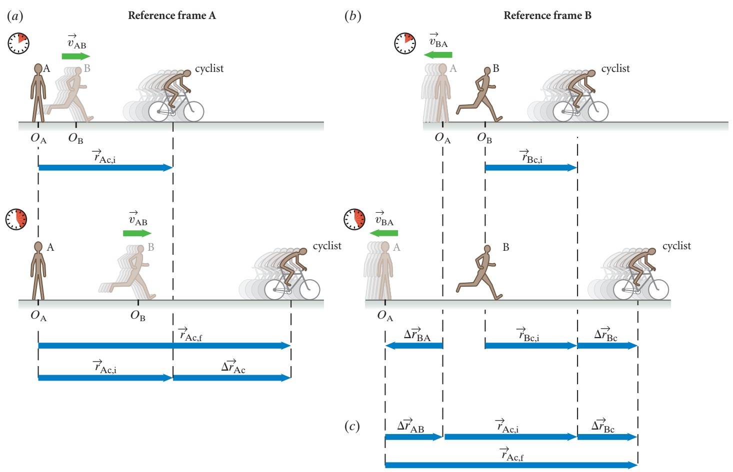
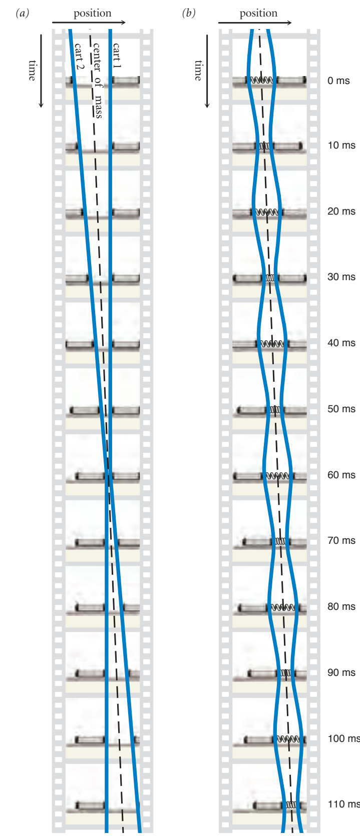
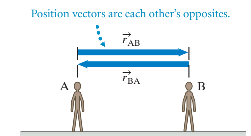
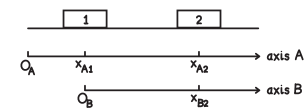

(a) Earth reference frame (observer E)
car 2
car 1
E
M
Relative to observer E, car 2 is at rest and car 1 moves to the right.
(b) Reference frame of car 1 (observer M)
car 2
car 1
But relative to observer M, car 1 is at rest while car 2, observer E, and the earth move to the left.

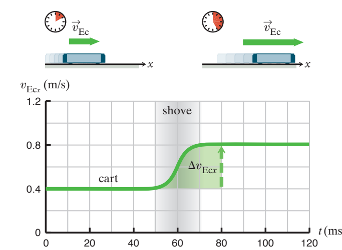

(a) Earth reference frame
cart 2
cart 1
t (ms)
(b) Reference frame M (v_{EMx} = −0.20 m/s)
cart 2
cart 1
t (ms)

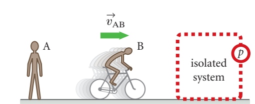

(a) Reference frame A
cyclist
A
B
(b) Reference frame B
cyclist
(c)

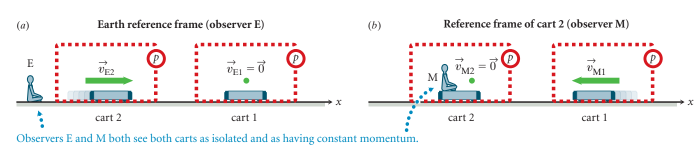

(a) position
time
cart 2
center of mass
cart 1
(b) position
time
0 ms
10 ms
20 ms
30 ms
40 ms
50 ms
60 ms
70 ms
80 ms
90 ms
100 ms
110 ms

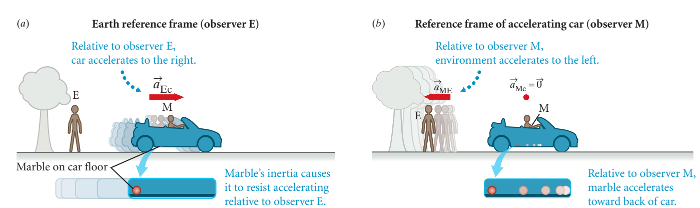

Position vectors are each other's opposites.
A
B

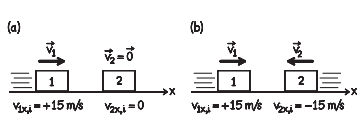

1
2
axis A
axis B

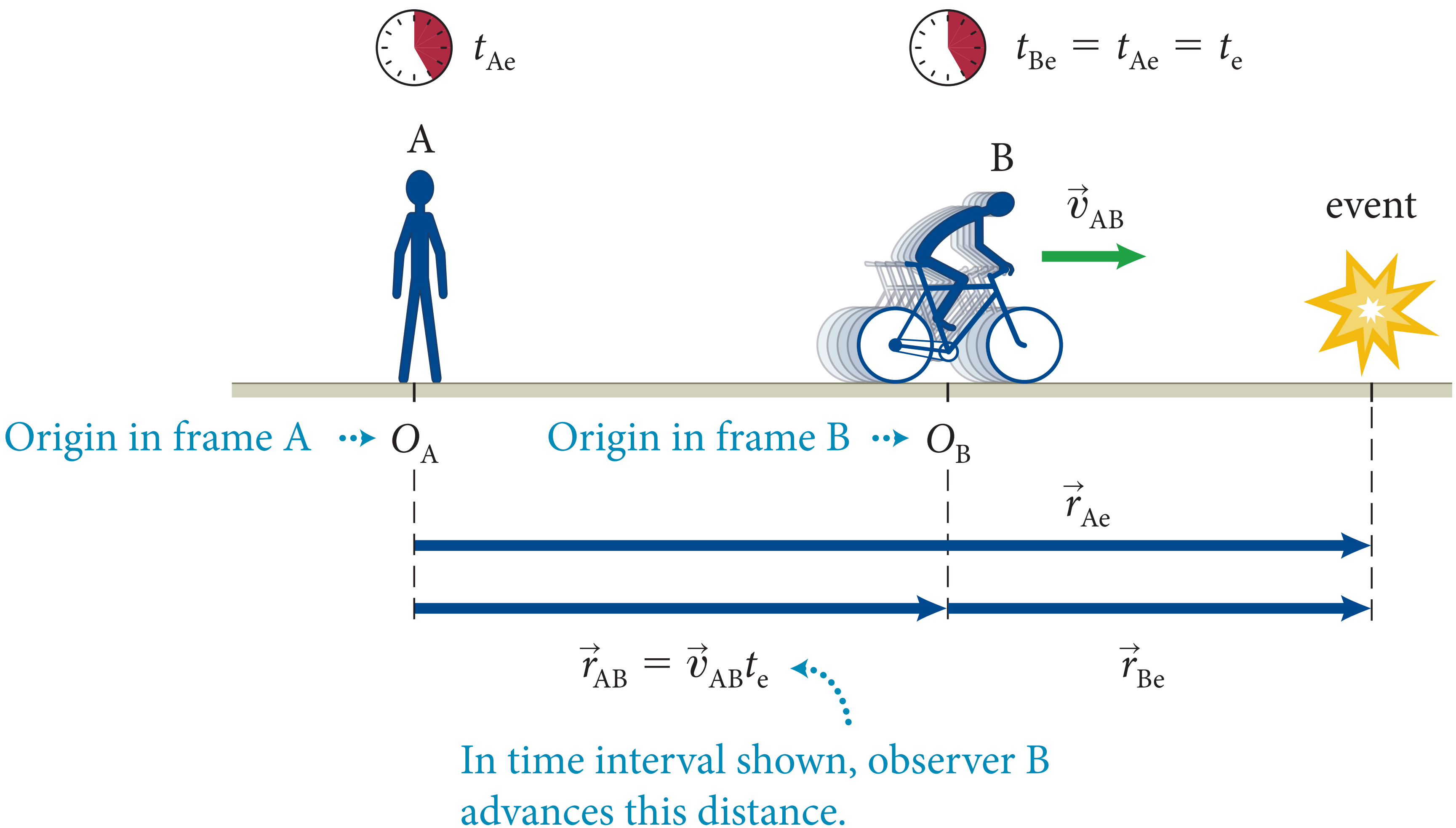

shove
cart
t (ms)


A
B
isolated system


(a) Earth reference frame (observer E)
E
cart 2
cart 1
(b) Reference frame of cart 2 (observer M)
M
cart 2
cart 1
Observers E and M both see both carts as isolated and as having constant momentum.

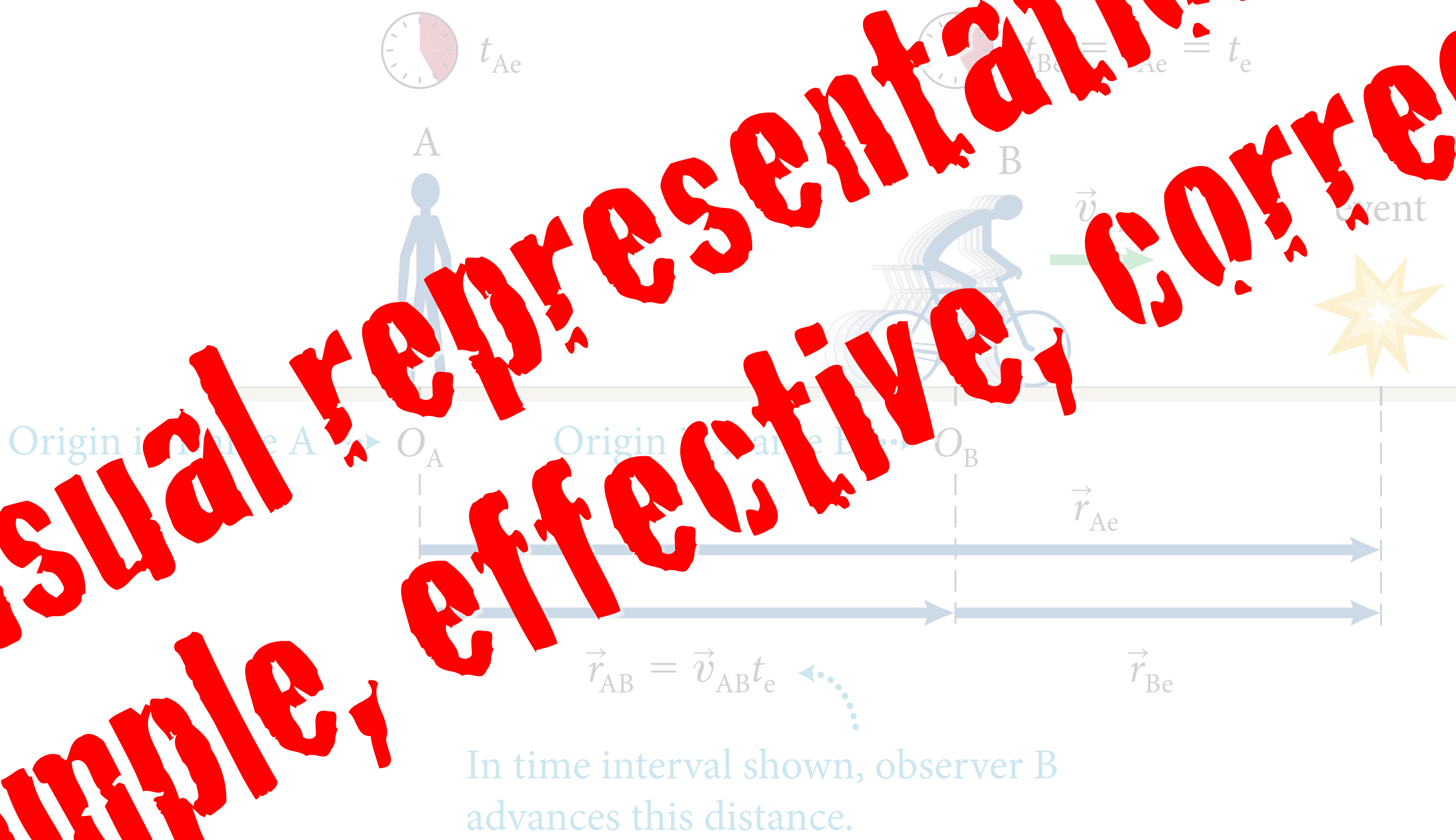

(a) Earth reference frame (observer E)
Relative to observer E, car accelerates to the right.
E
M
Marble on car floor
Marble's inertia causes it to resist accelerating relative to observer E.
(b) Reference frame of accelerating car (observer M)
Relative to observer M, environment accelerates to the left.
E
M
Relative to observer M, marble accelerates toward back of car.


(a)
1
2
$v_{1x,i}$ = +15 m/s
$v_{2x,i}$ = 0
(b)
1
2
$v_{1x,i}$ = +15 m/s
$v_{2x,i}$ = −15 m/s



t_{Ae}
$t_{Be} = t_{Ae} = t_e$
A
B
$\vec{v}_{AB}$
event
Origin in frame A
O_A
Origin in frame B
O_B
$\vec{r}_{Ae}$
$\vec{r}_{AB} = \vec{v}_{AB} t_e$
$\vec{r}_{Be}$
In time interval shown, observer B advances this distance.

visual representations: simple, effective, correct



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PRINCIPLES VOLUME

- concepts before quantitative tools
- checkpoints to thinking
- 4-step worked examples
- research-based illustrations
- research-based pedagogy

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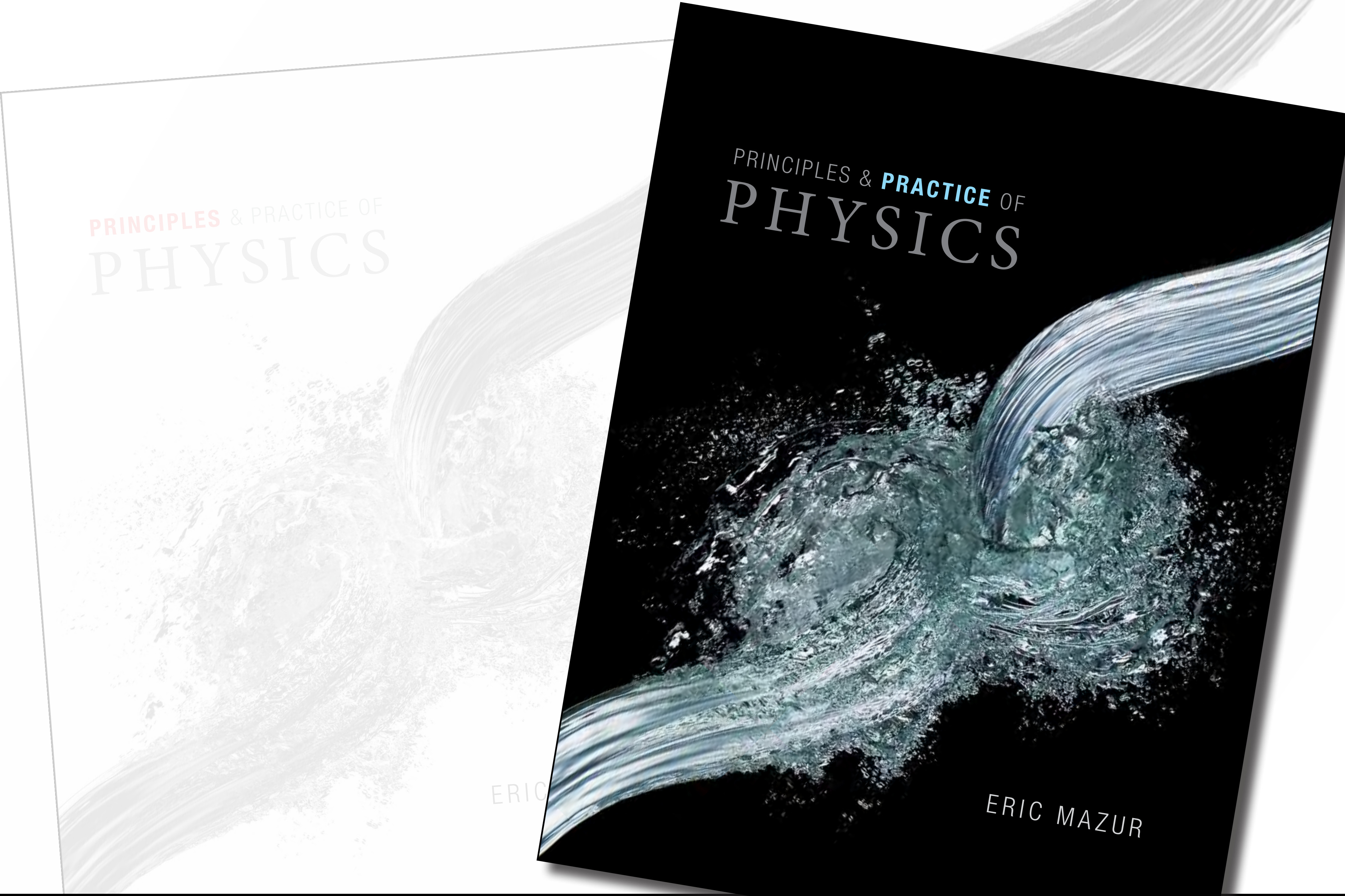

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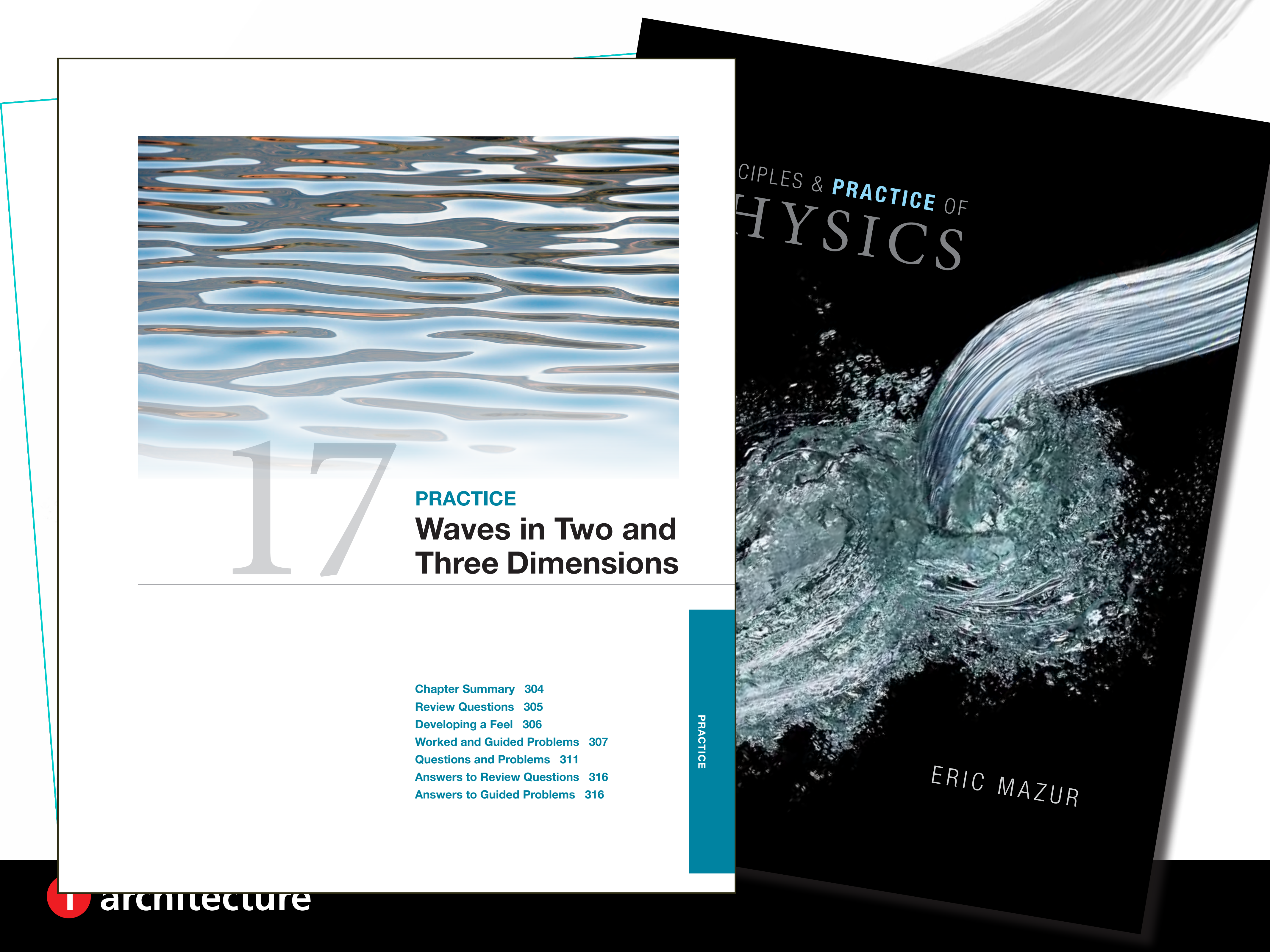
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Waves in Two and Three Dimensions

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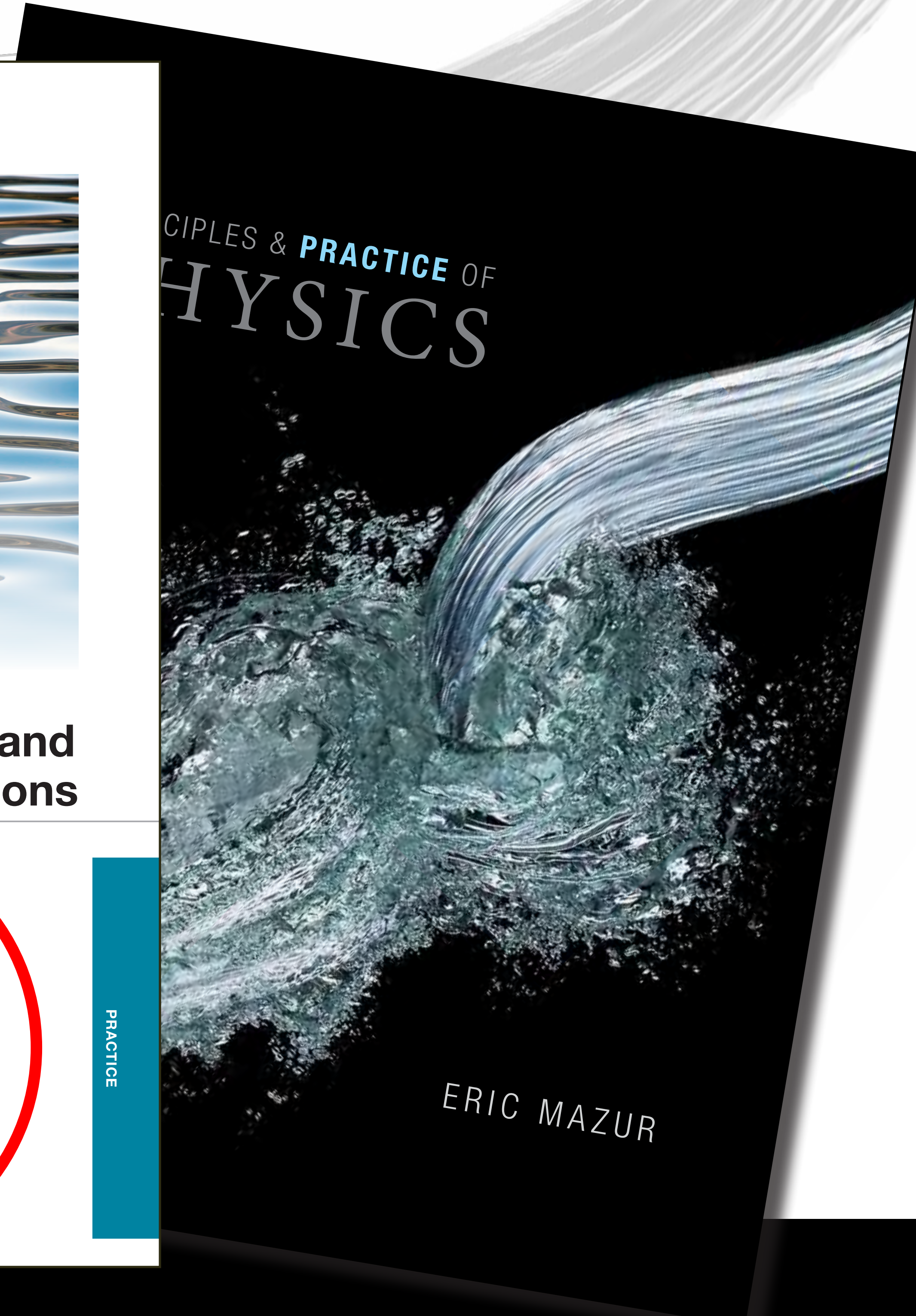

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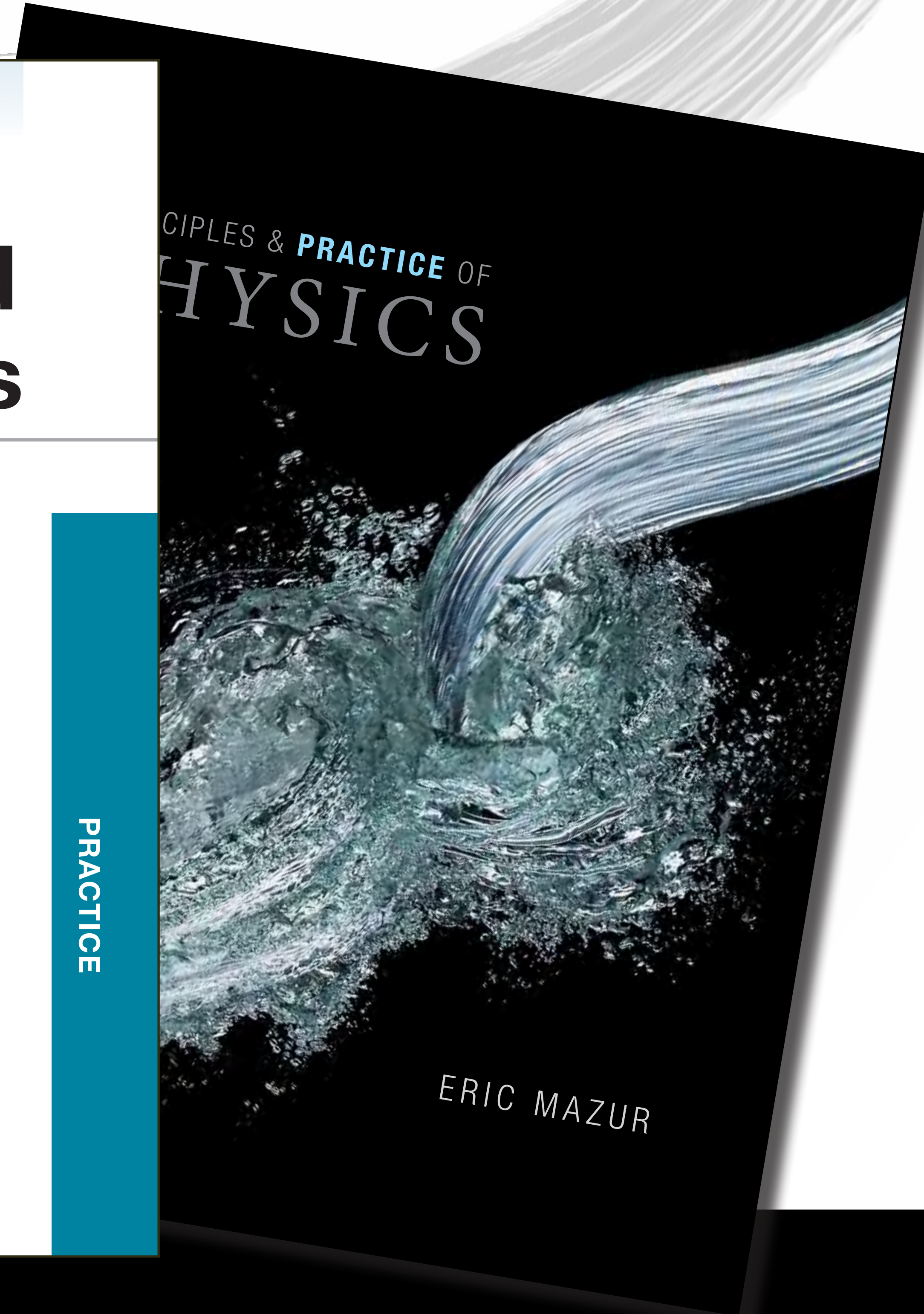

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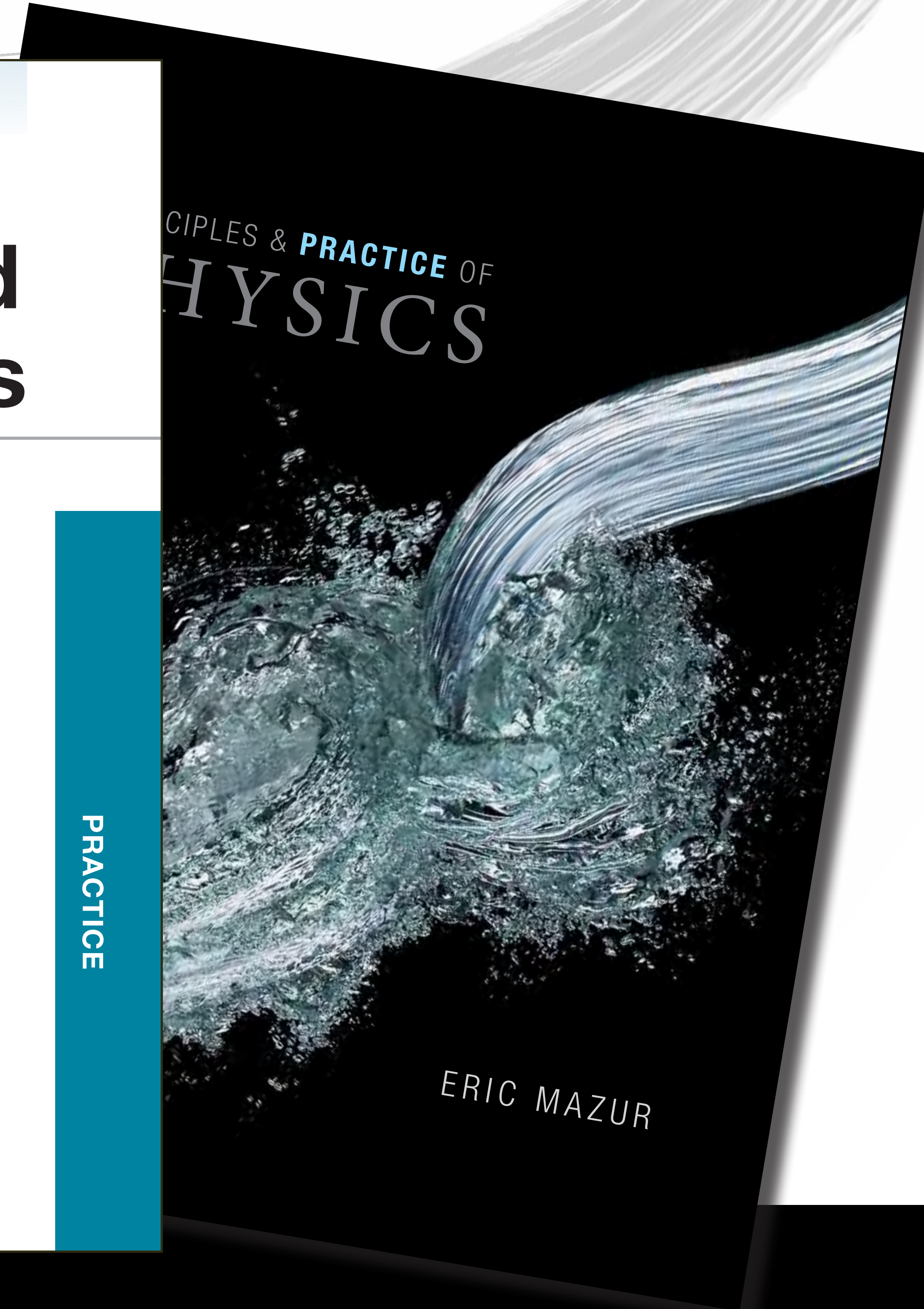

PRACTICE

Waves in Two
Three Dimens

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2. The rotational inertia of a bowling ball about an axis tangent to its surface (A, R, X)
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10. The kinetic energy of a spinning yo-yo (K, W, J, Q)

Hints

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 revolution around the Sun?
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 orbit?
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?
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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?
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V. What is your inertia?
W. When thrown, how long a time interval does the yo-yo take to reach the end of the string?
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, $\sum \vec{F} = m\vec{a}$, 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.** $6 \times 10^{-5}\ \text{kg} \cdot \text{m}^2$ (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 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.** $8 \times 10^{-3}\ \text{m/s}^2$; **U.** $\omega \approx 10\ \text{s}^{-1}$; **V.** 7×10^1 kg; **W.** 0.5 s; **X.** the parallel-axis theorem; **Y.** 3×10^1 mi/h; **Z.** 6×10^{24} kg; **AA.** 3×10^1 m/s

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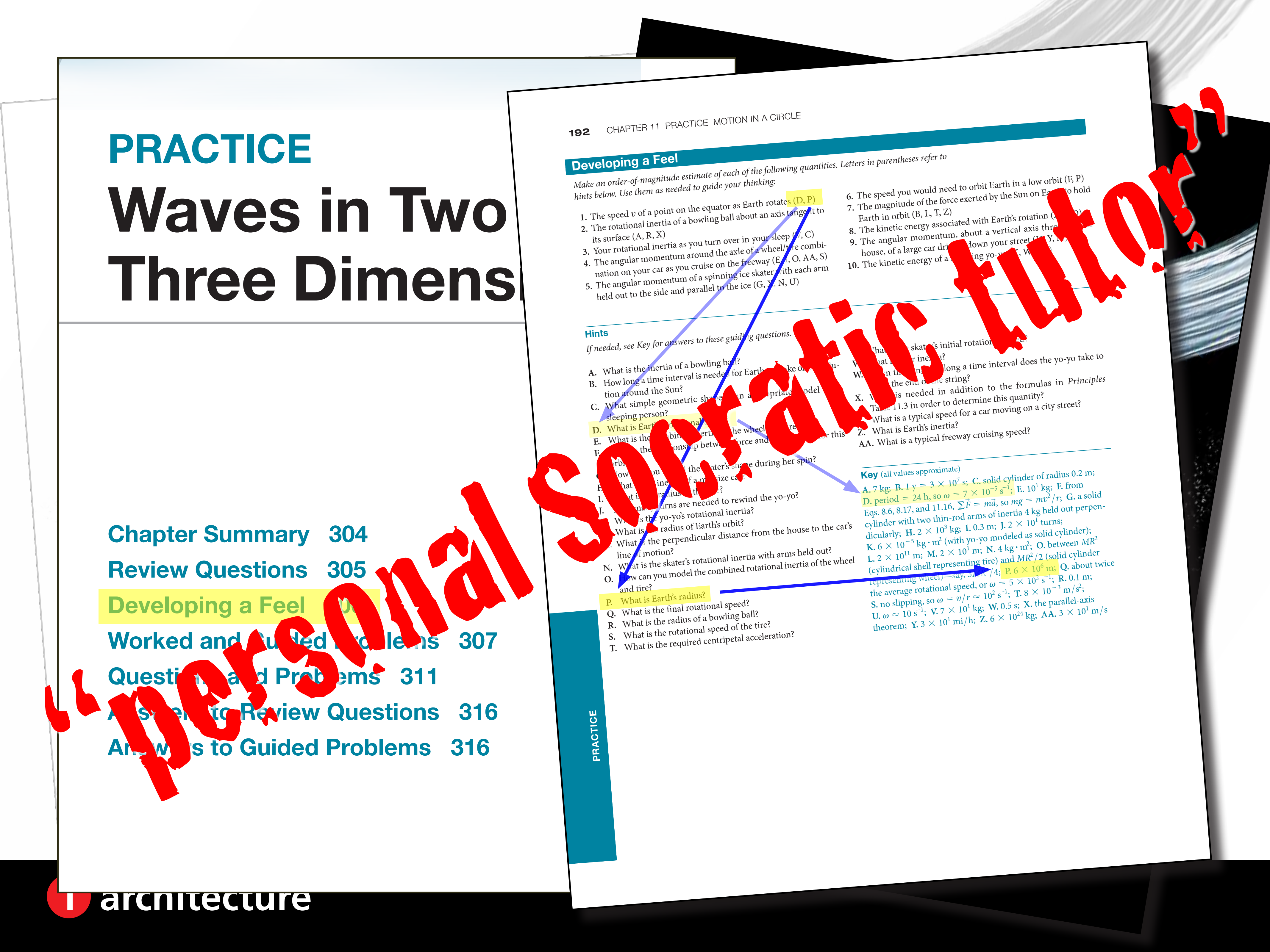

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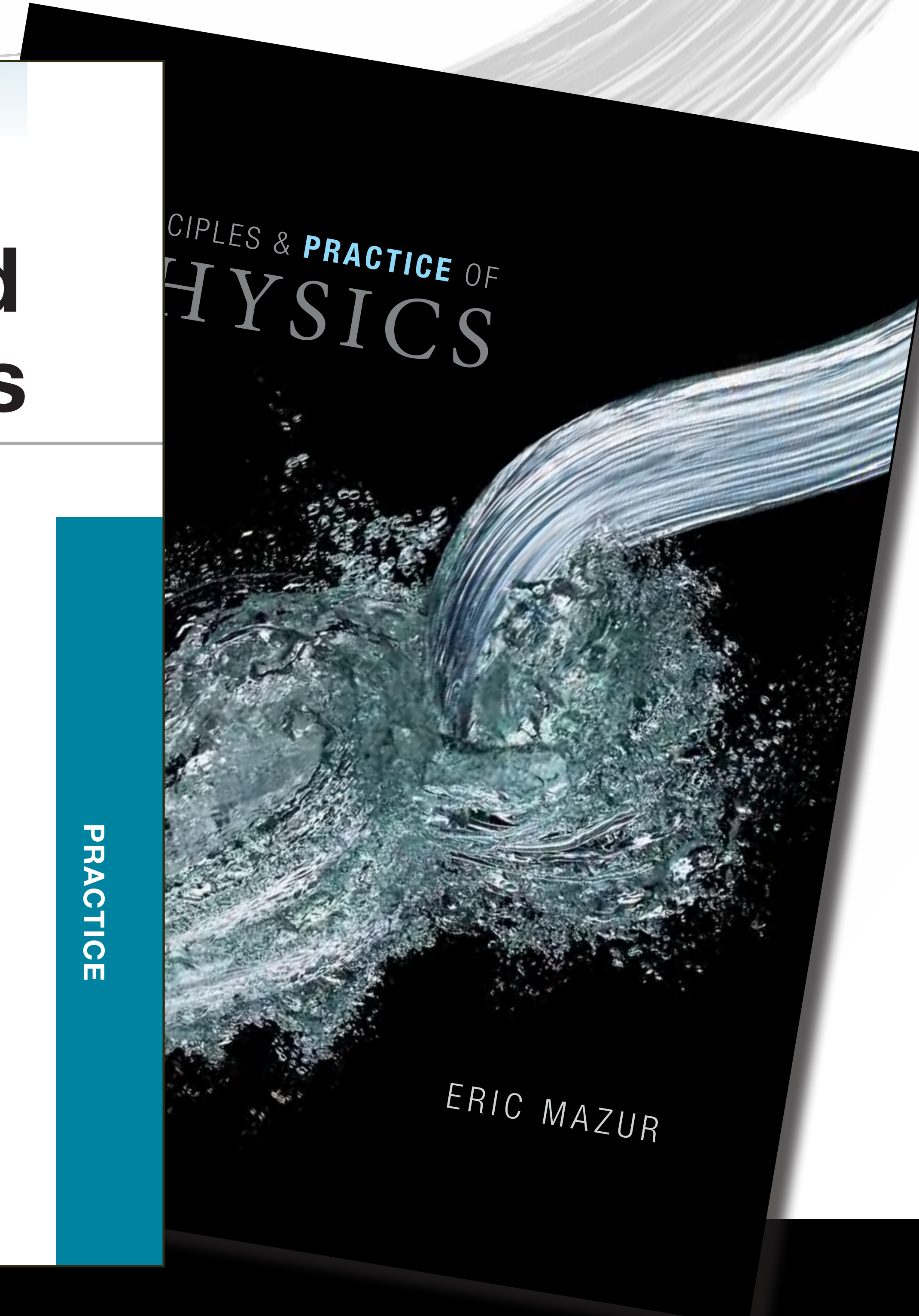

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Worked Problem 13.3 Escape at last

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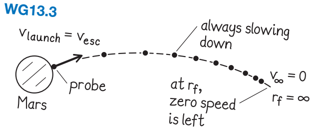

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$$\tfrac{1}{2} v_{esc}^2 = G\frac{m_M}{R_M}$$

$$v_{esc} = \sqrt{2G\frac{m_M}{R_M}}$$

$$v_{esc} = \sqrt{2(6.67 \times 10^{-11}\,\mathrm{N \cdot m^2/kg^2})\frac{6.42 \times 10^{23}\,\mathrm{kg}}{3.40 \times 10^{6}\,\mathrm{m}}}$$
$$= 5.02 \times 10^3\,\mathrm{m/s} = 5\,\mathrm{km/s}. ✔$$

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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PRACTICE

Guided Problem 13.4 Spring to the stars

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3. How does the spacecraft gain the necessary escape speed?

❷ DEVISE PLAN

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❸ EXECUTE PLAN

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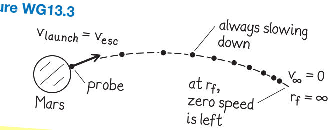

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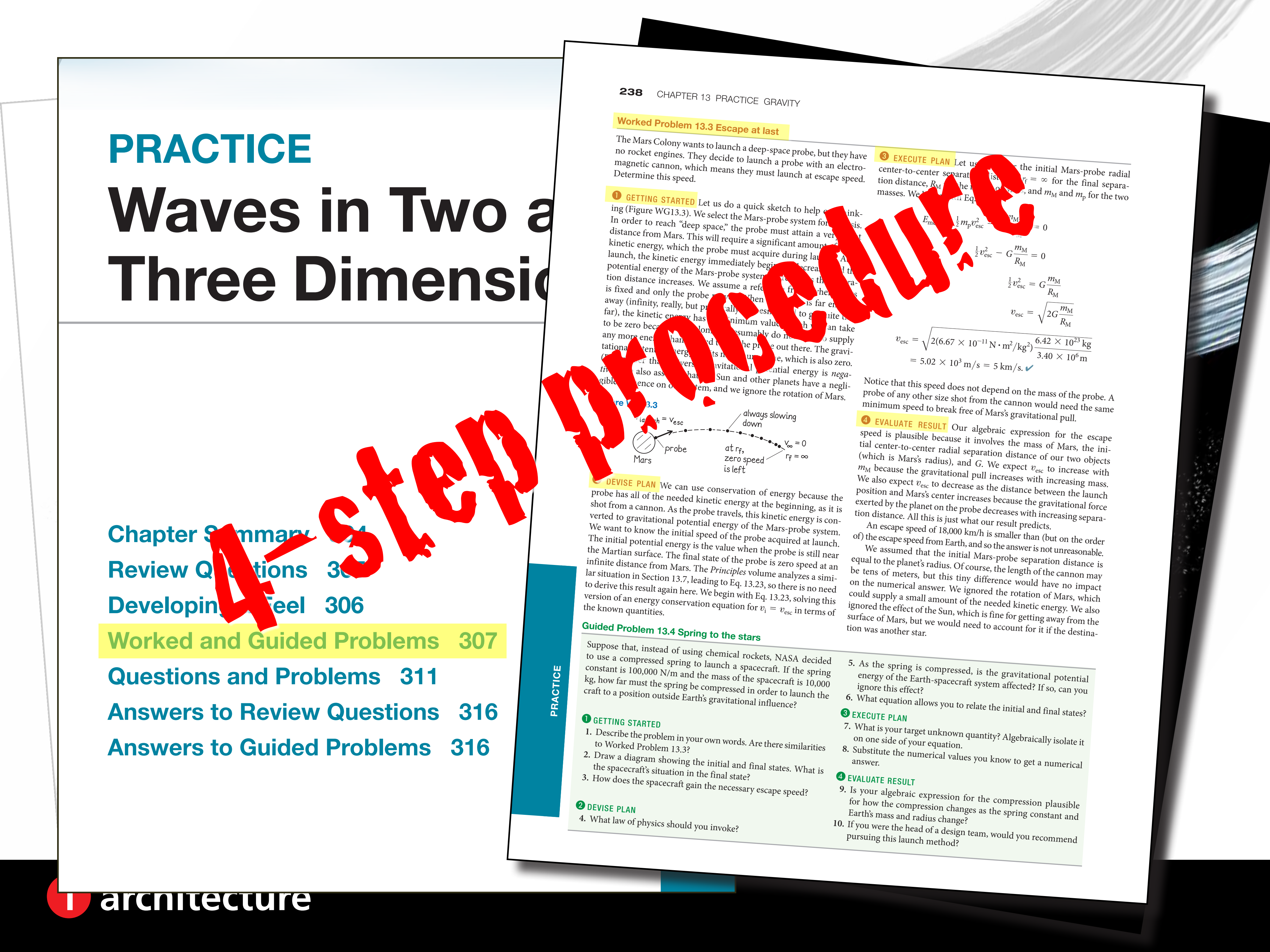
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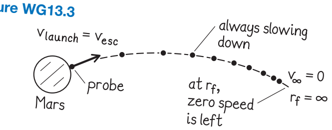

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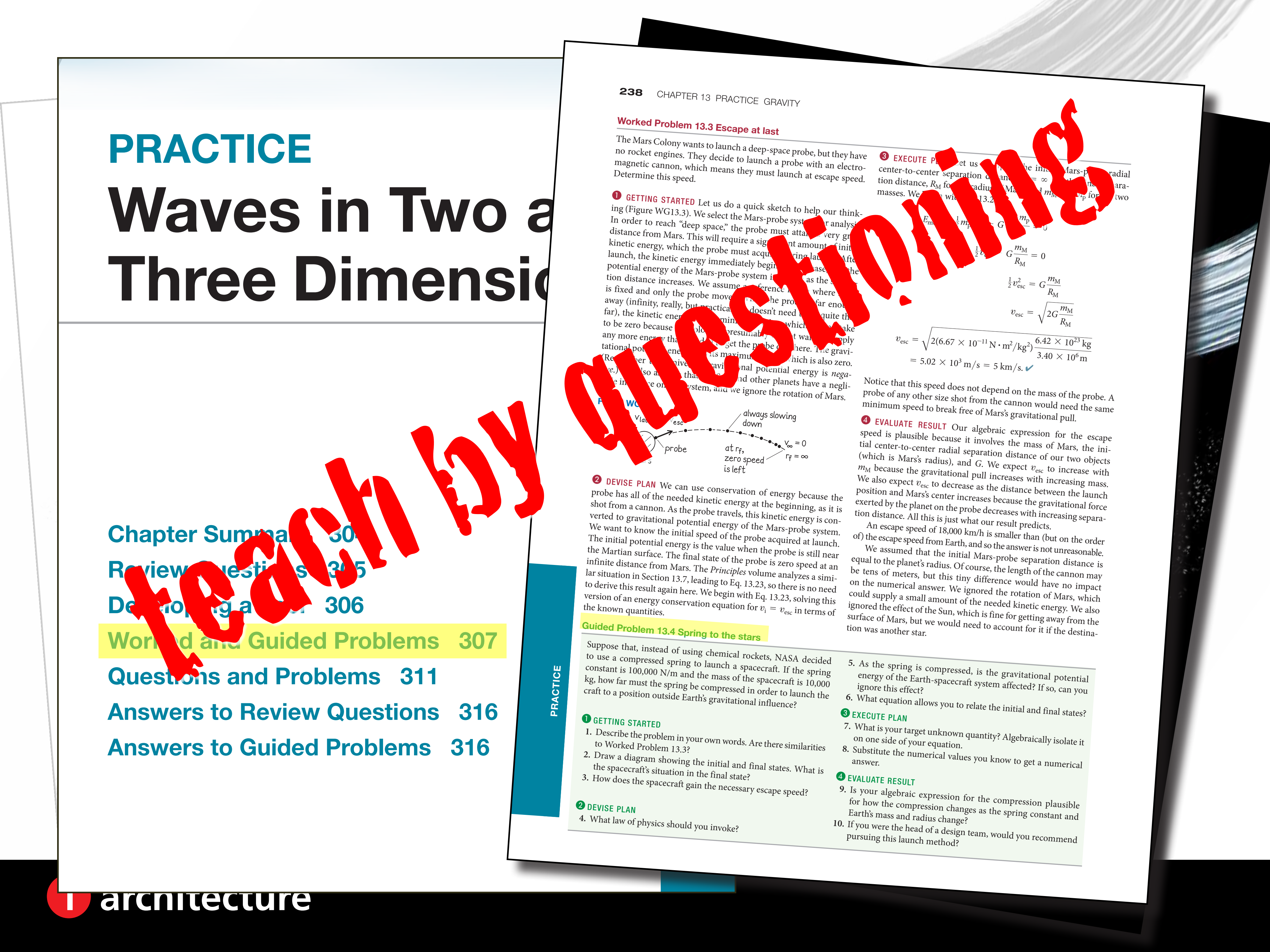

teach by questioning
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238 CHAPTER 13 PRACTICE GRAVITY
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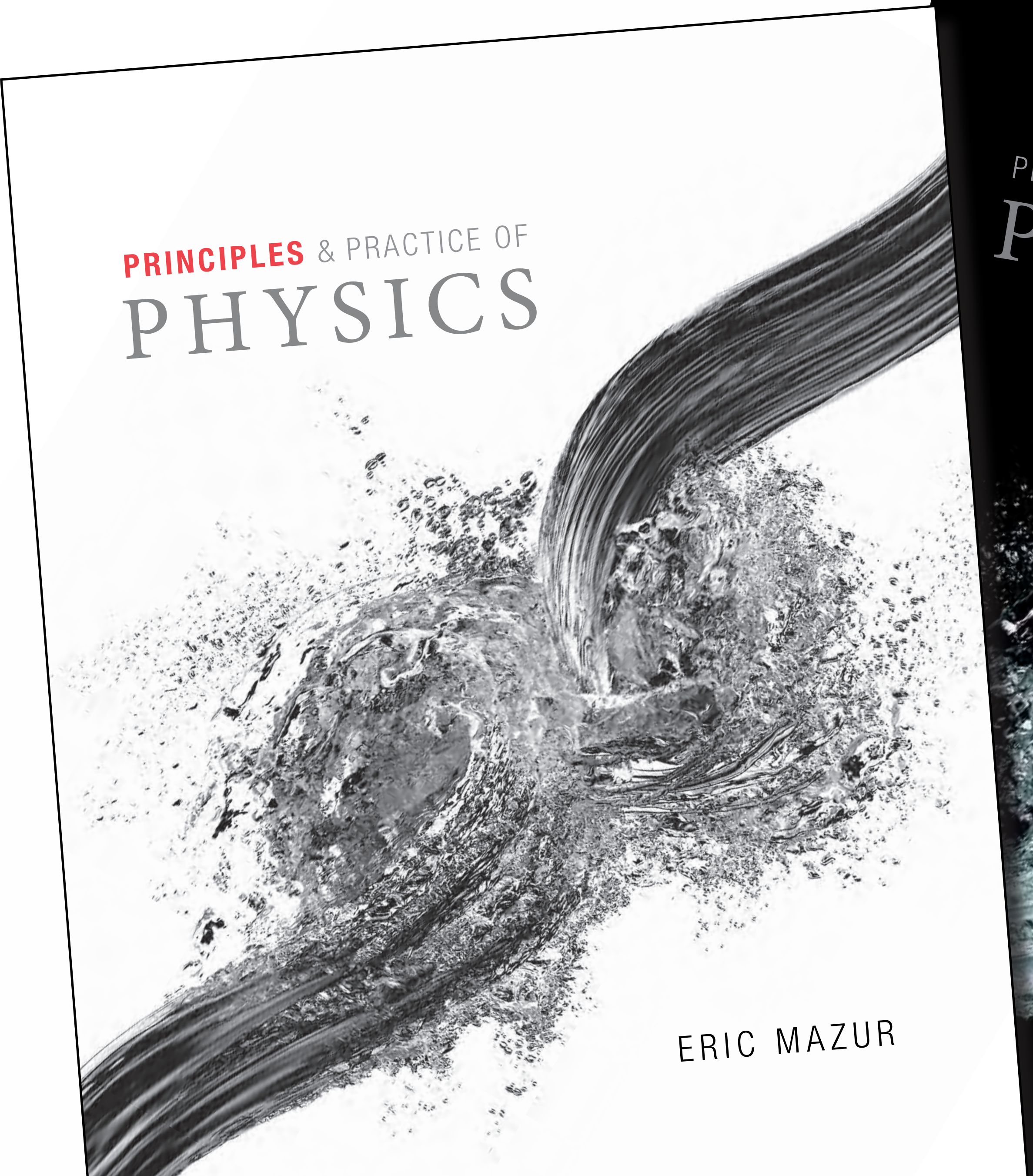
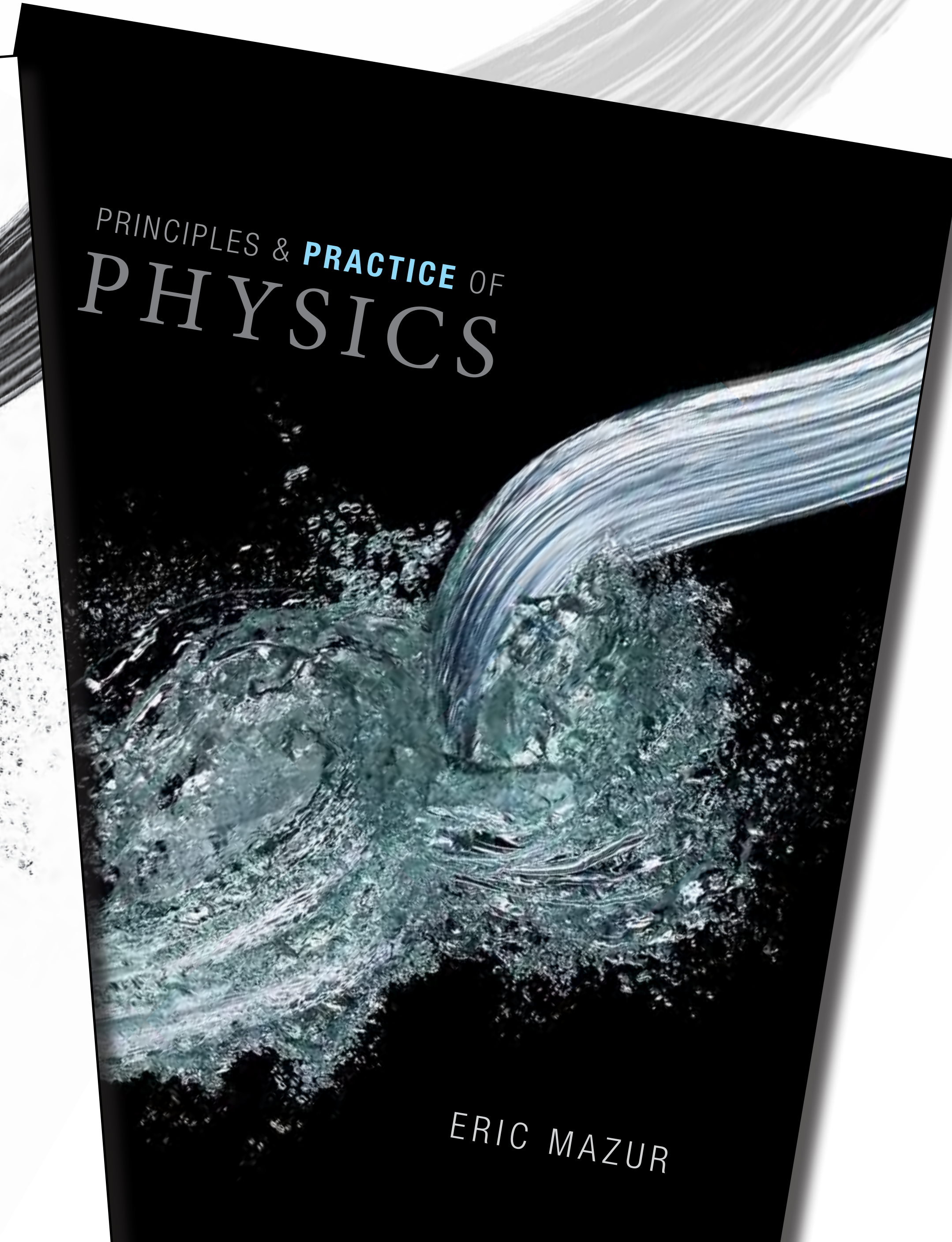
PRACTICE

PRACTICE VOLUME

- not just end-of-chapter material
- many innovative features
- teaches authentic problem solving

1 architecture





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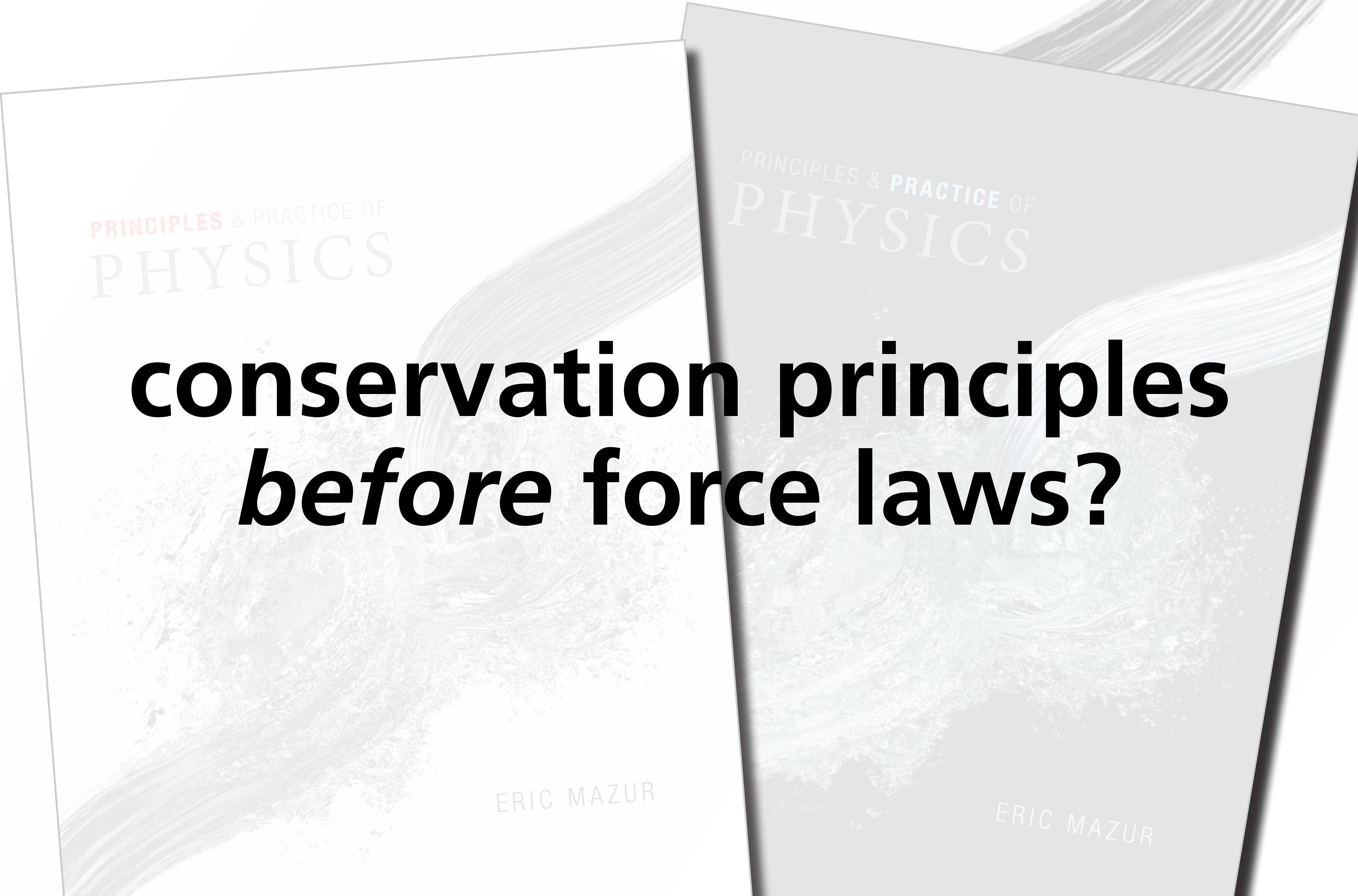
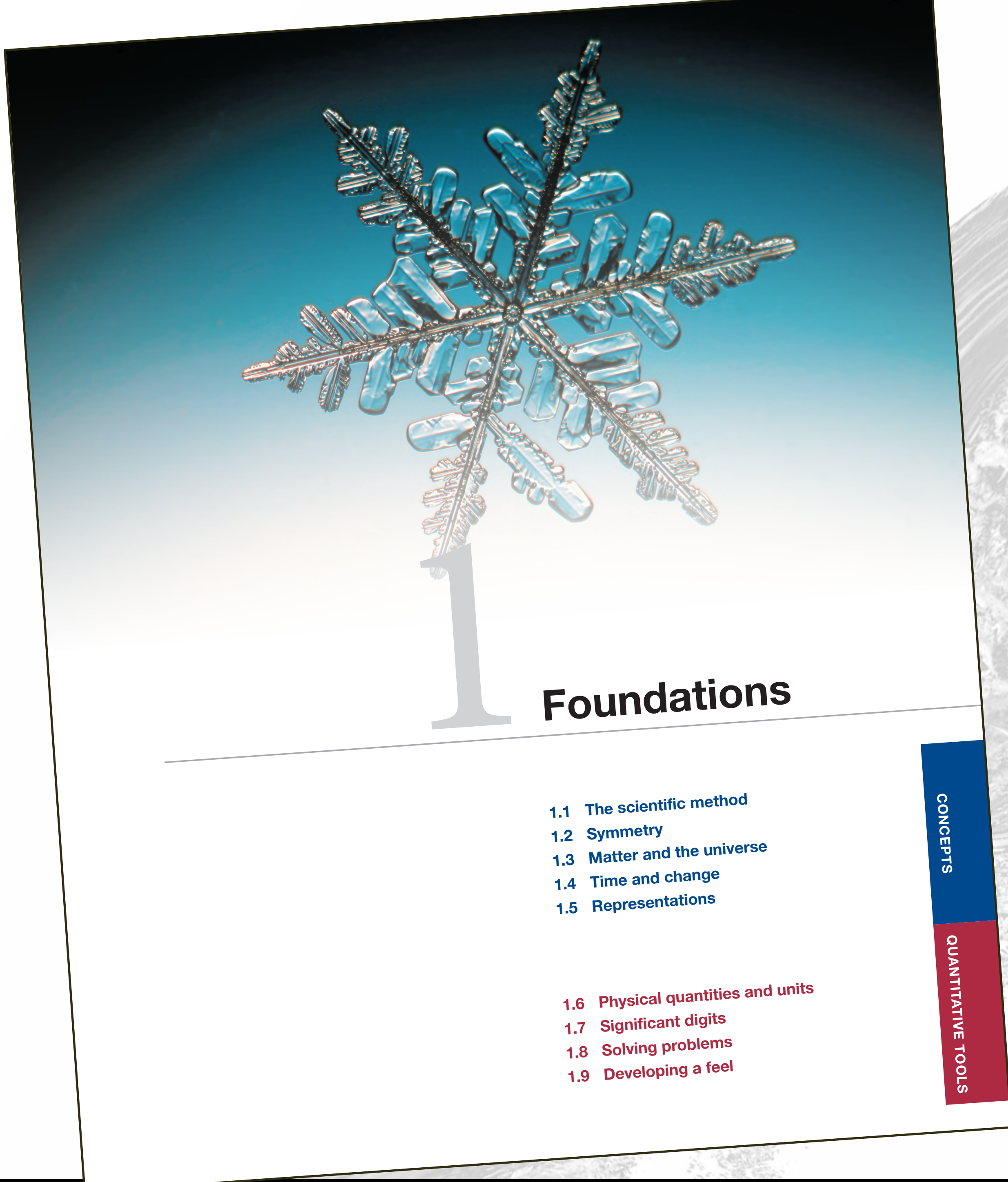


conservation principles *before* force laws?

❶ architecture ❷ content



1 Foundations

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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

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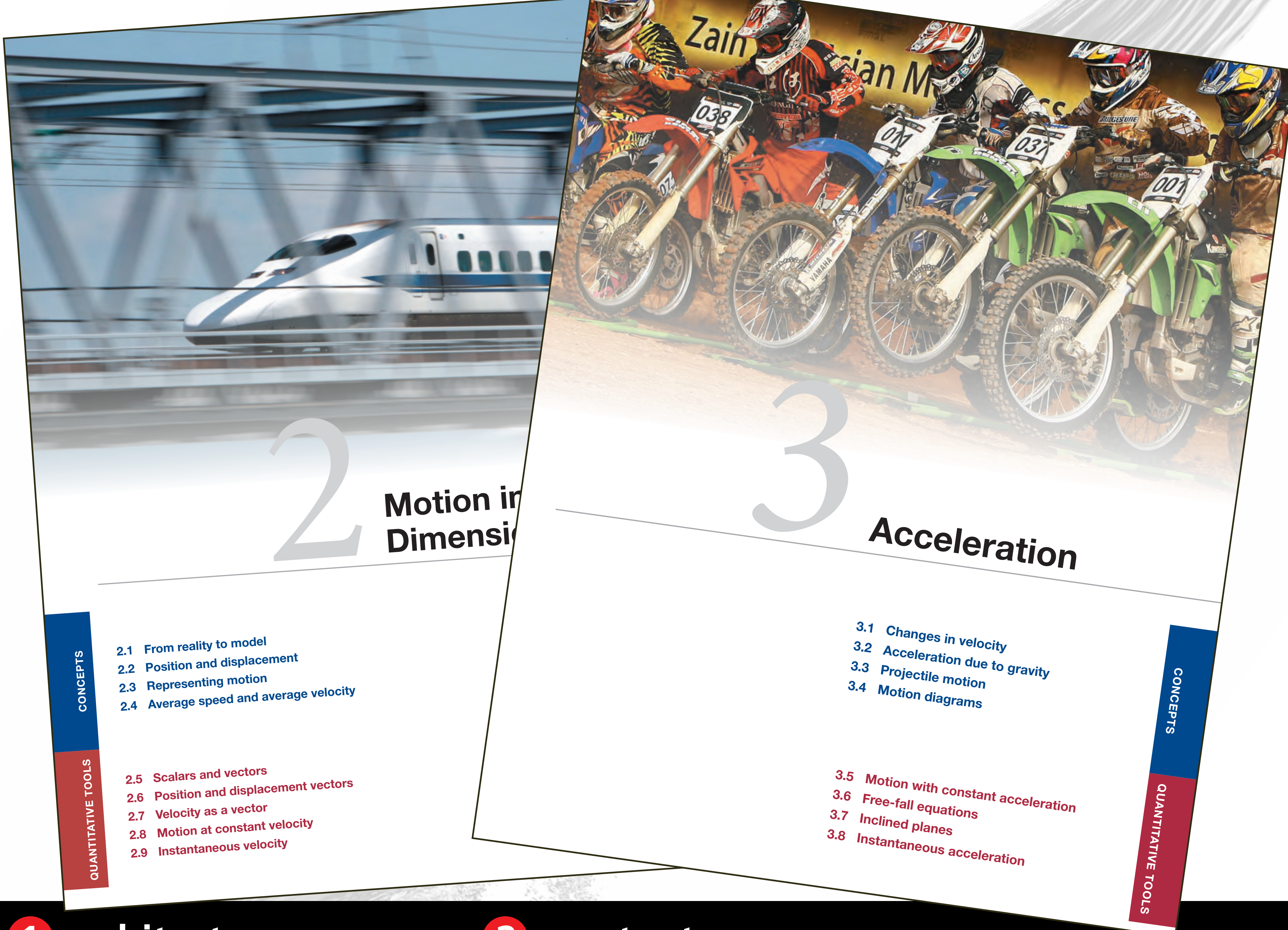

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2.1 From reality to model
2.2 Position and displacement
2.3 Representing motion
2.4 Average speed and average velocity

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2.5 Scalars and vectors
2.6 Position and displacement vectors
2.7 Velocity as a vector
2.8 Motion at constant velocity
2.9 Instantaneous velocity

3

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3.1 Changes in velocity
3.2 Acceleration due to gravity
3.3 Projectile motion
3.4 Motion diagrams

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3.5 Motion with constant acceleration
3.6 Free-fall equations
3.7 Inclined planes
3.8 Instantaneous acceleration

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4 Momentum

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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

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1 architecture

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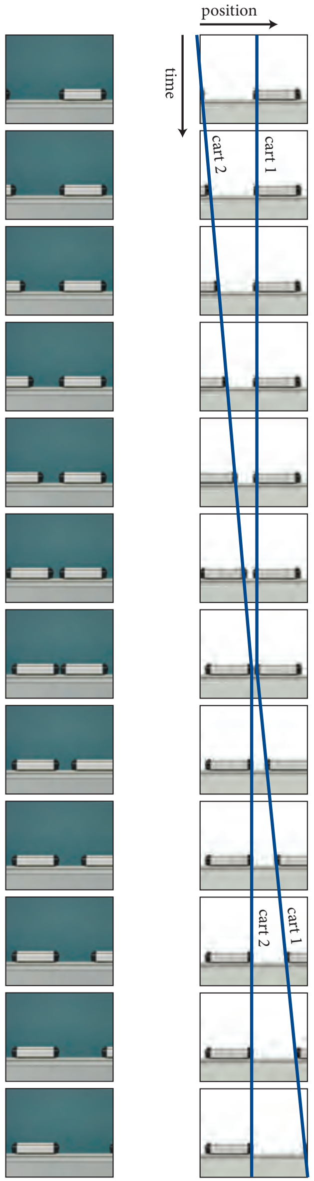

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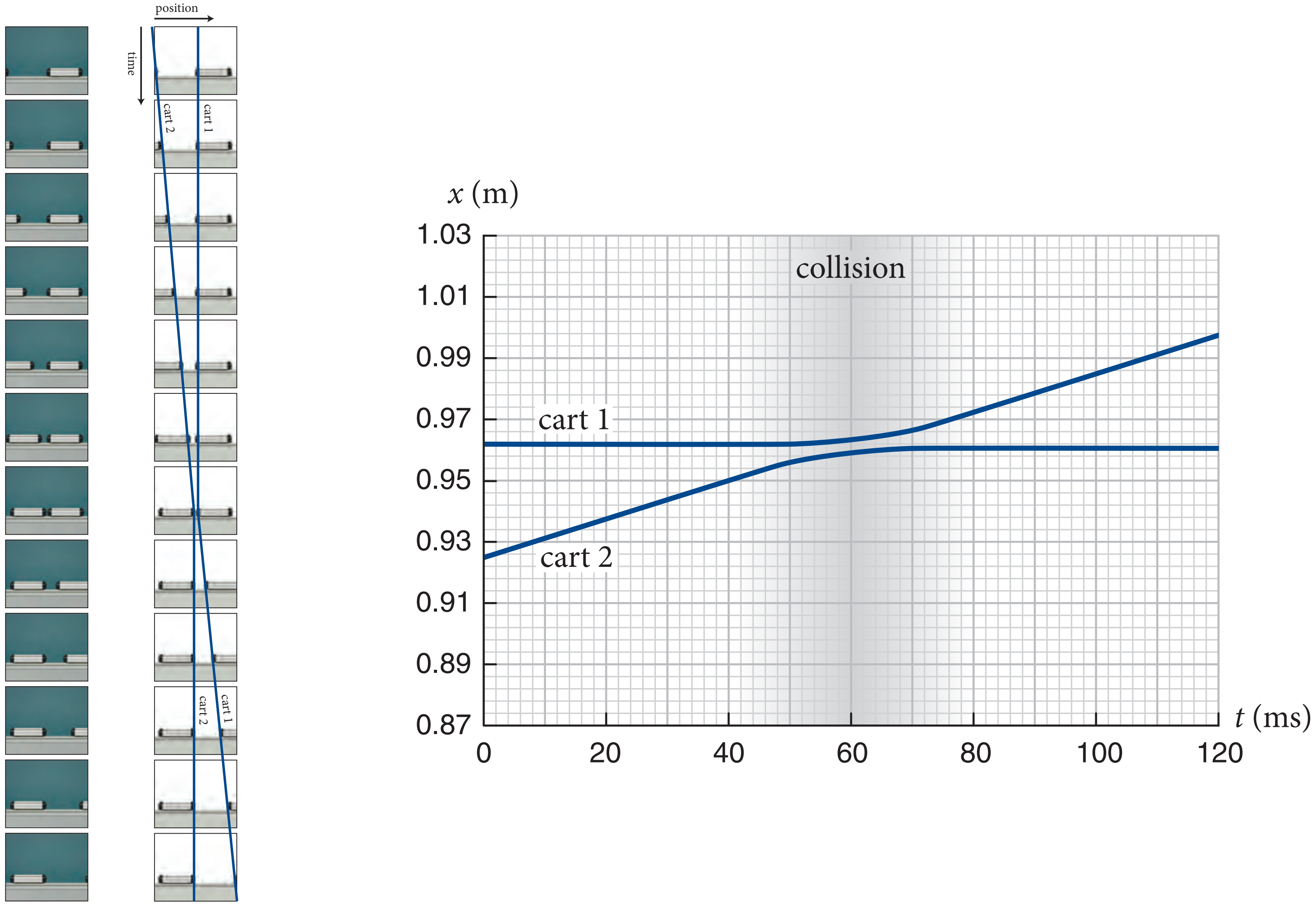

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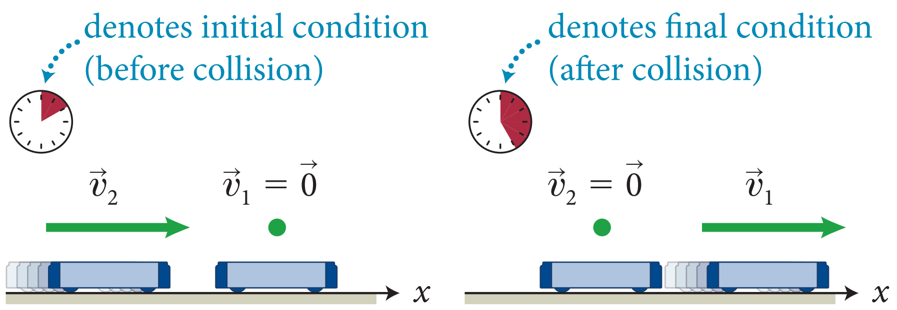

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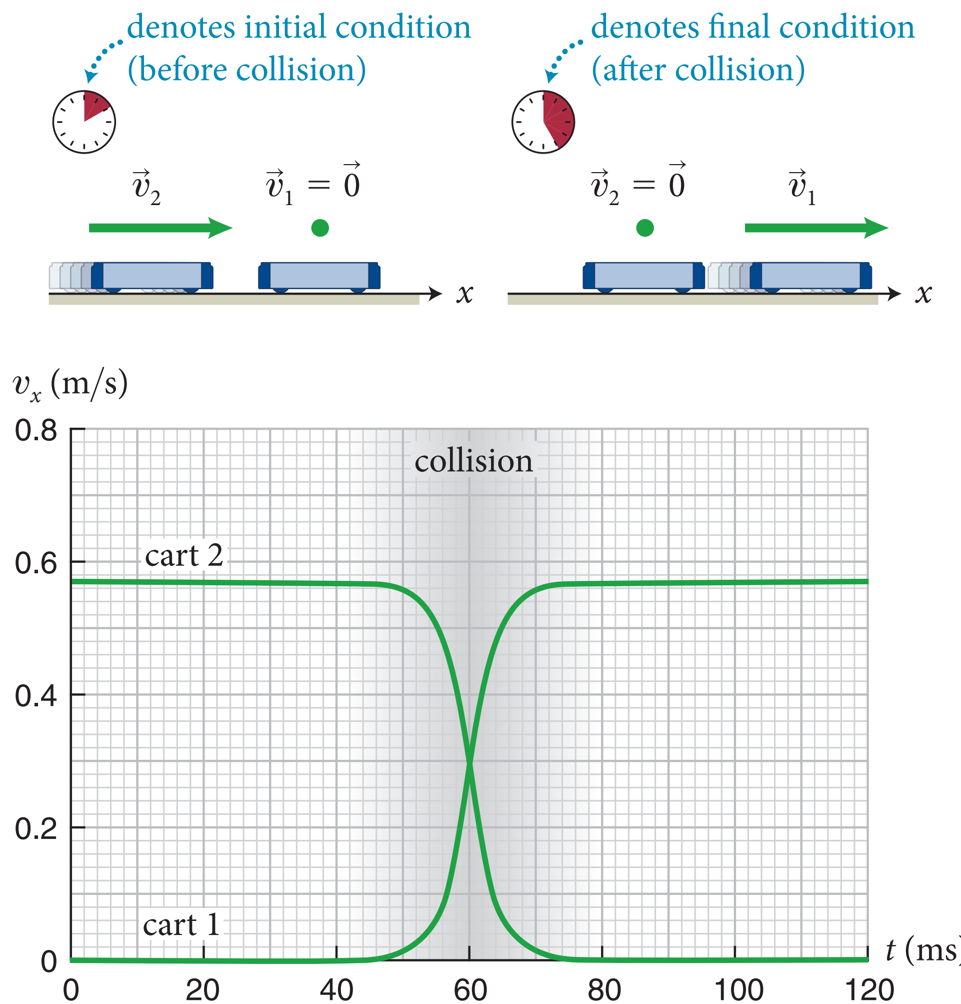

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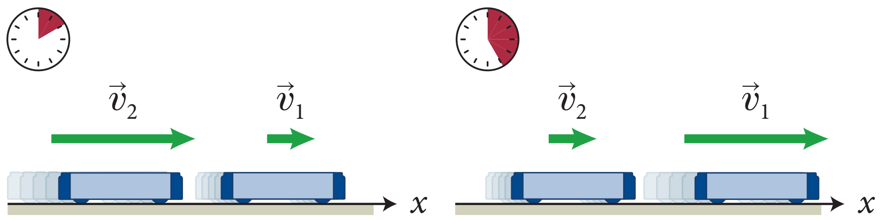

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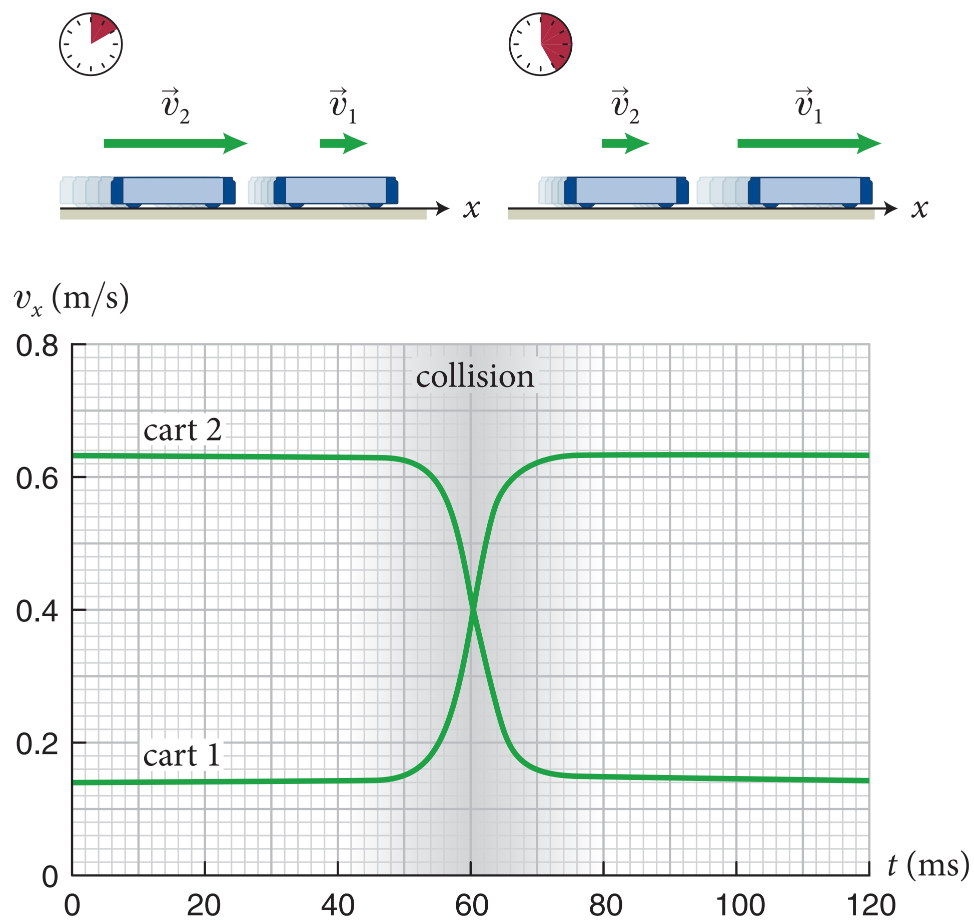

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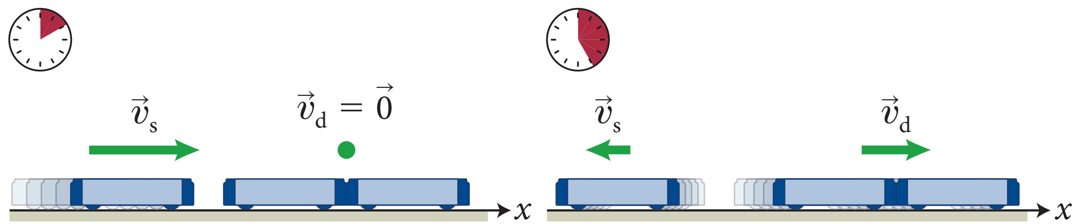

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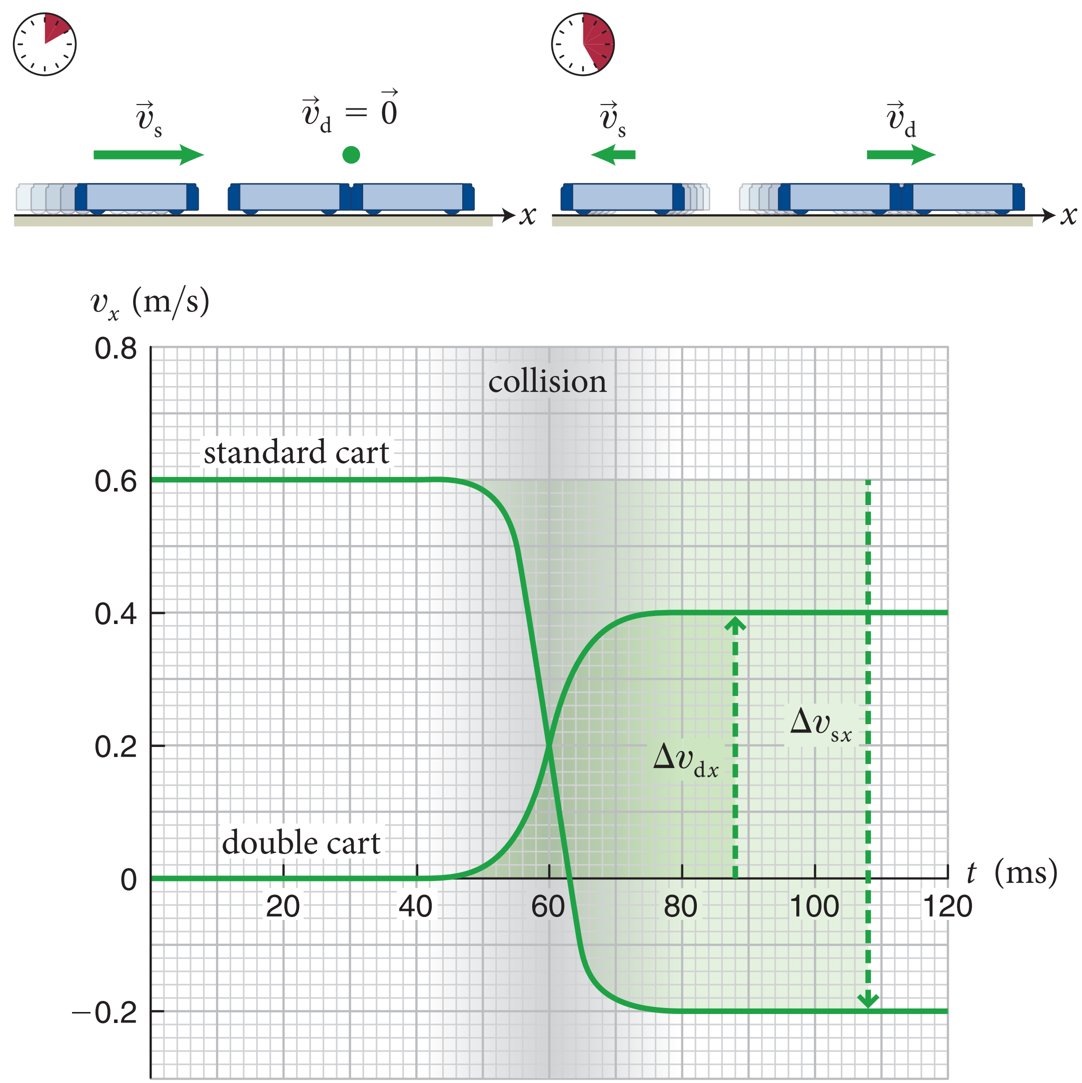

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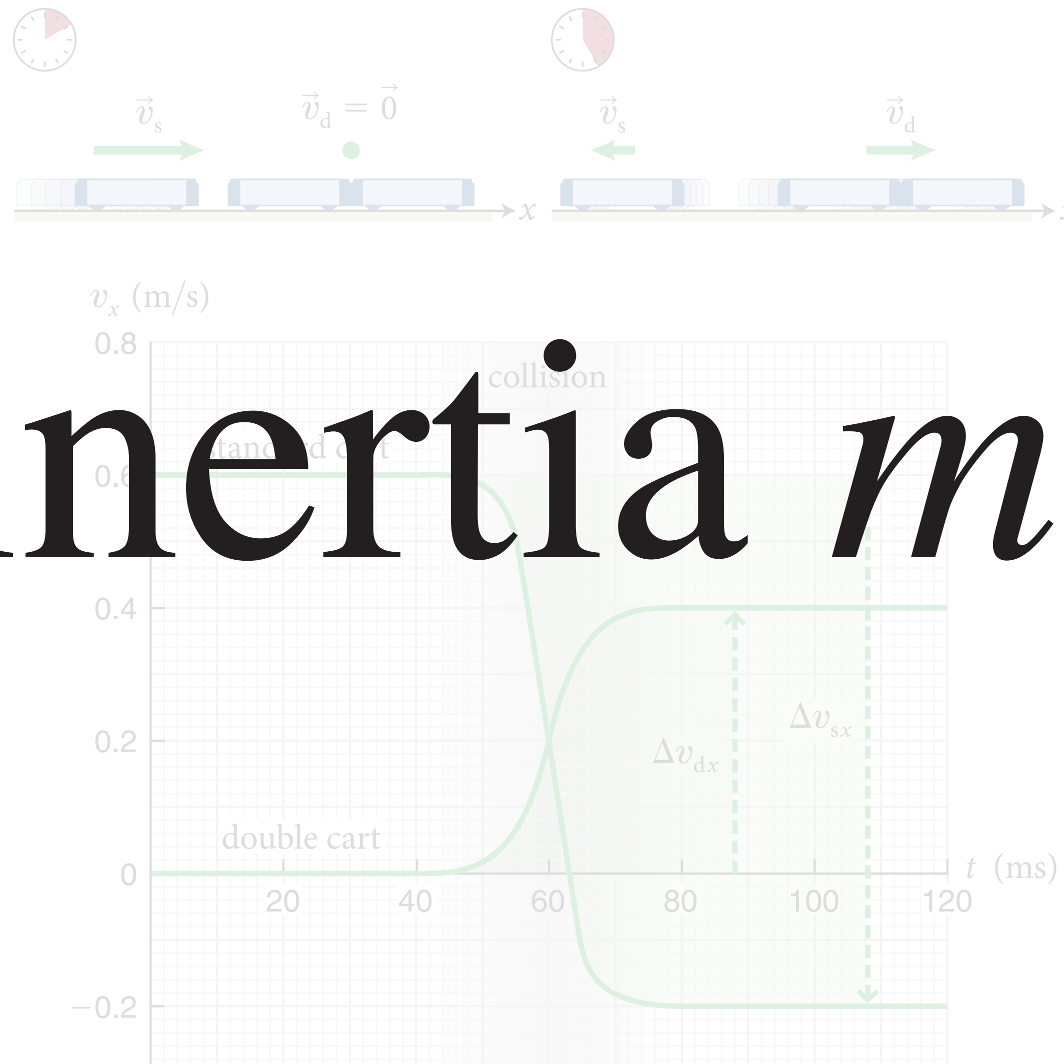
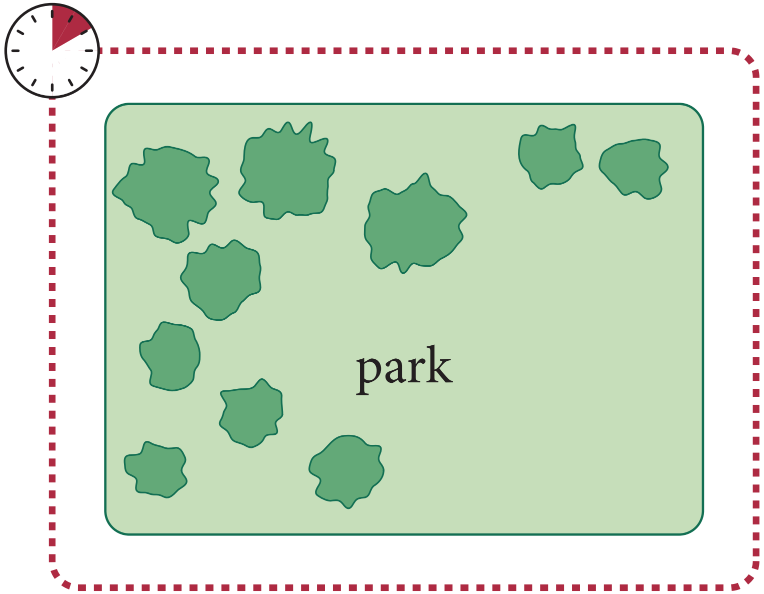


inertia m

1 architecture 2 content

systems & extensive quantities

systems & extensive quantities



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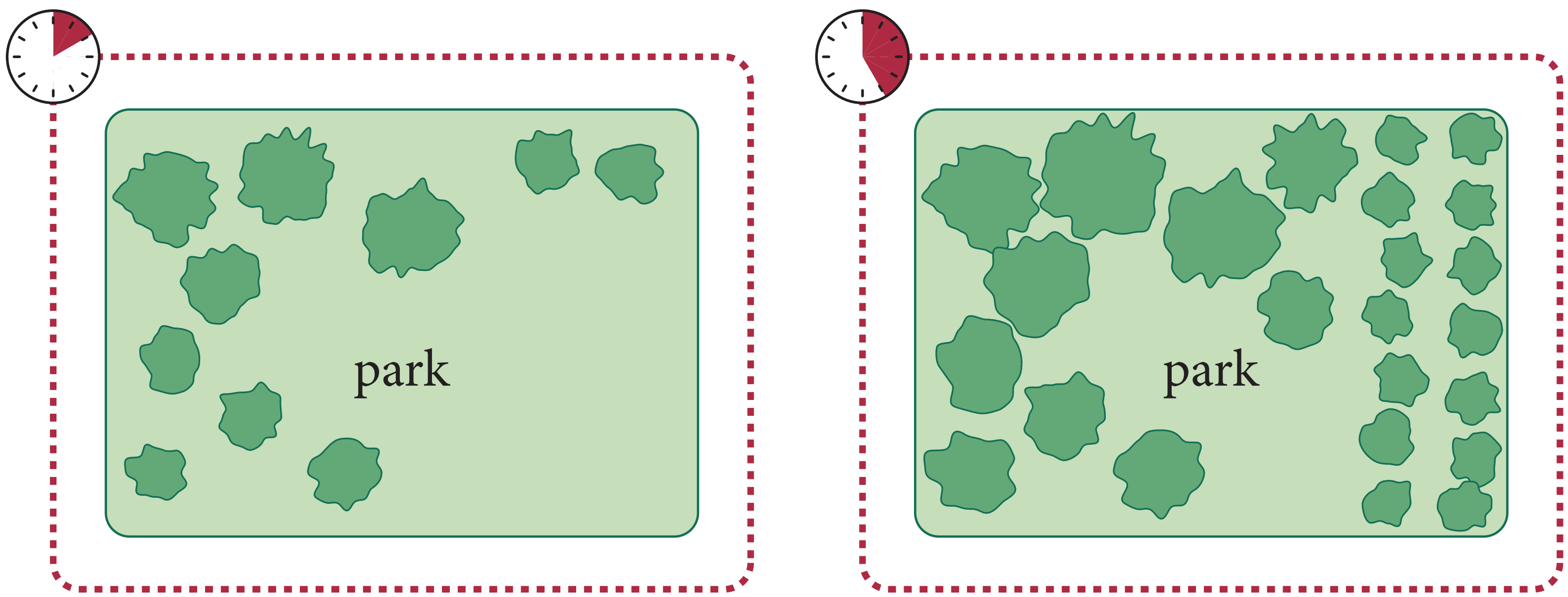
systems & extensive quantities



systems & extensive quantities

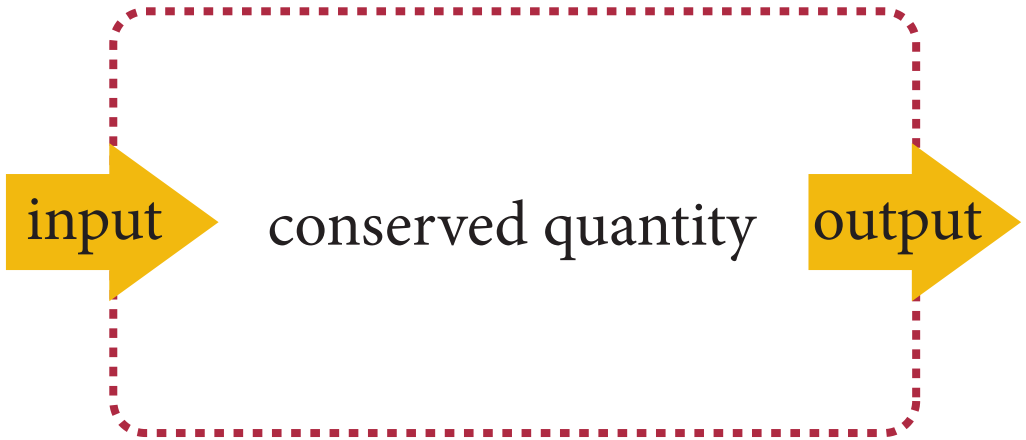
systems & extensive quantities

1 architecture 2 content

systems & extensive quantities

1 architecture
2 content

systems & extensive quantities



1 architecture

2 content

systems & extensive quantities

conserved quantity

systems & extensive quantities

conserved quantity in isolated system

conserved quantity

can’t change (constant)

systems & extensive quantities

conserved qu

cons

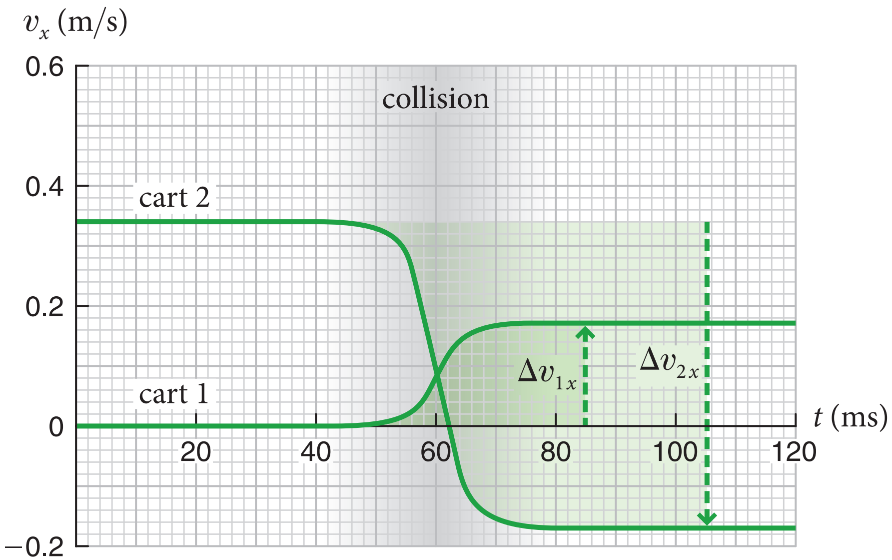
can’t change (

“When do you address systems that are not closed/isolated?”

systems & extensive quantities

$$\vec{p} \equiv m\vec{v}$$

conserved quantity



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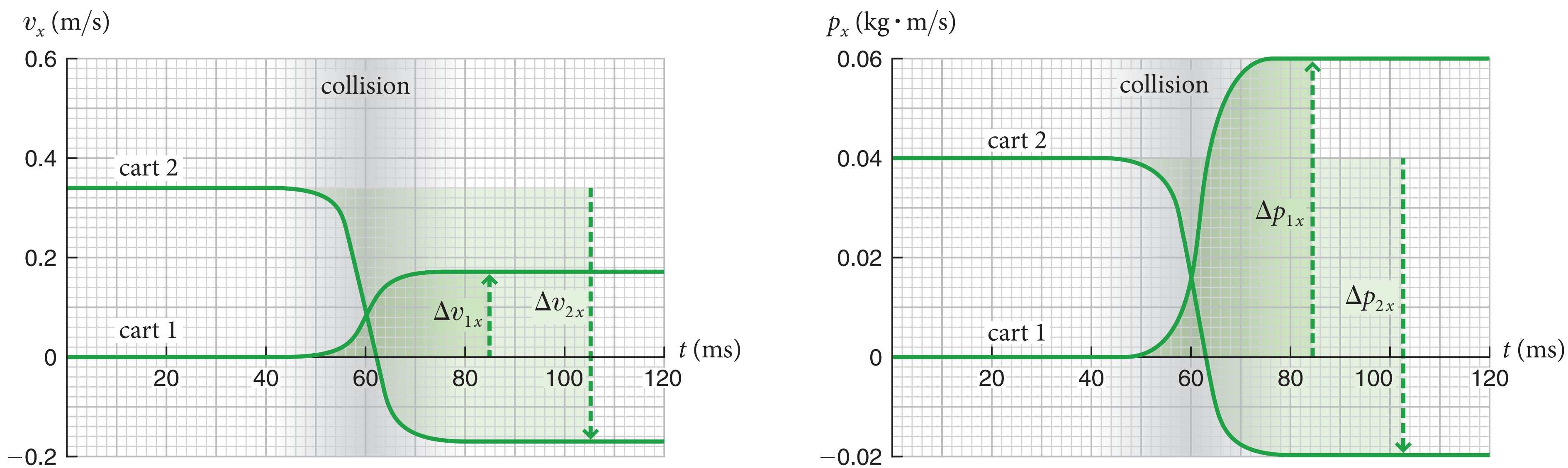

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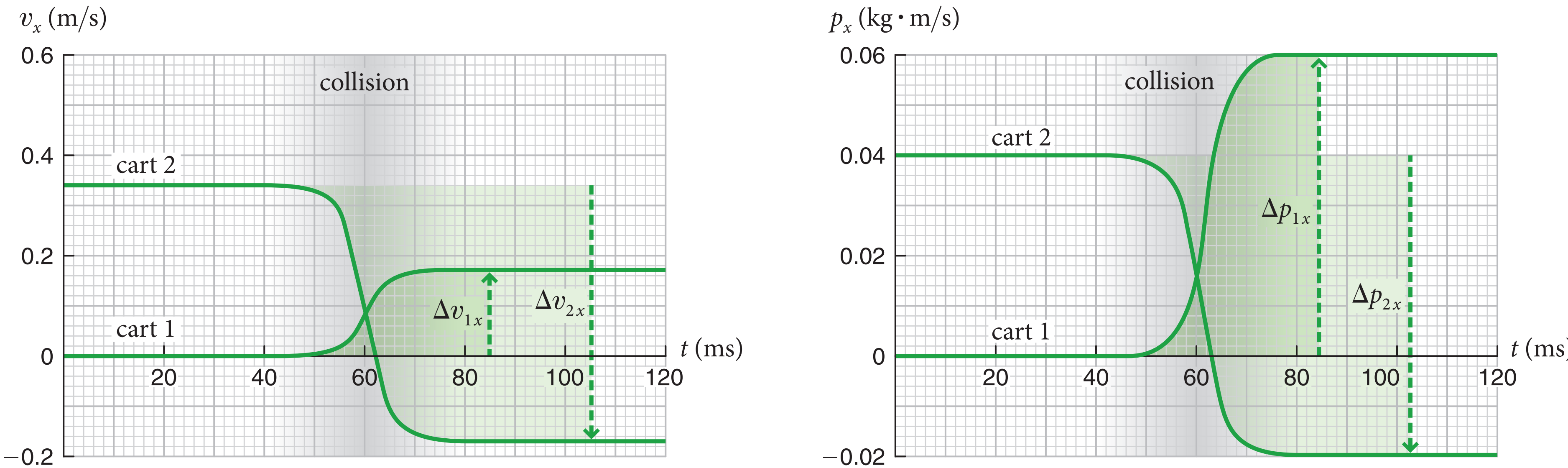
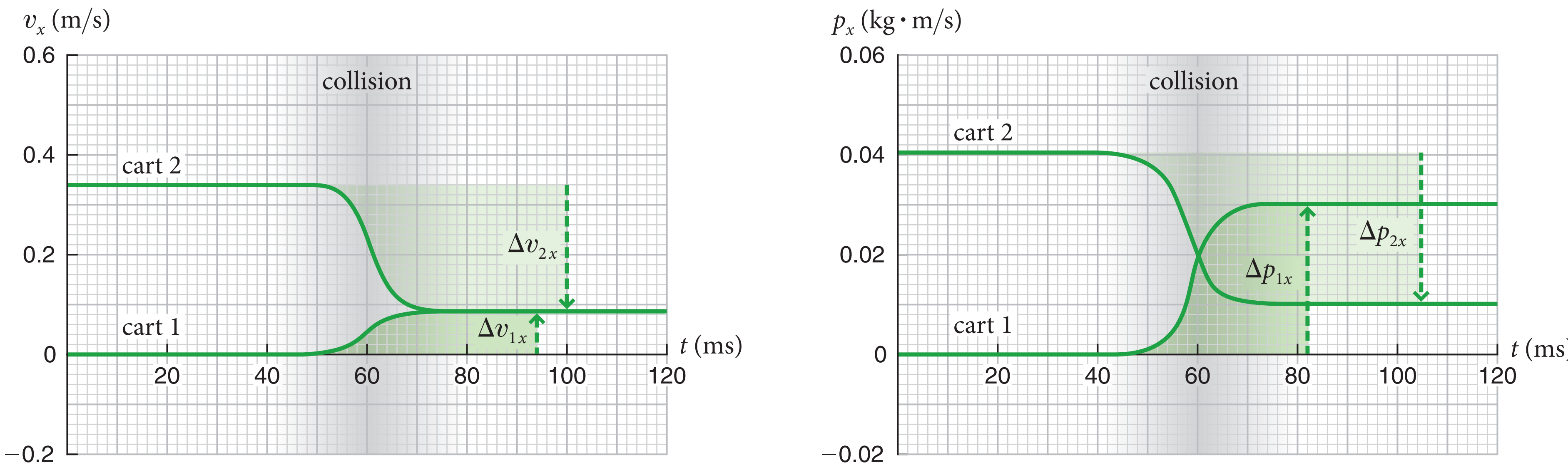


$$\Delta\vec{p} \equiv \Delta\vec{p}_1 + \Delta\vec{p}_2 = \vec{0}.$$

1 architecture **2** content



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

1 architecture

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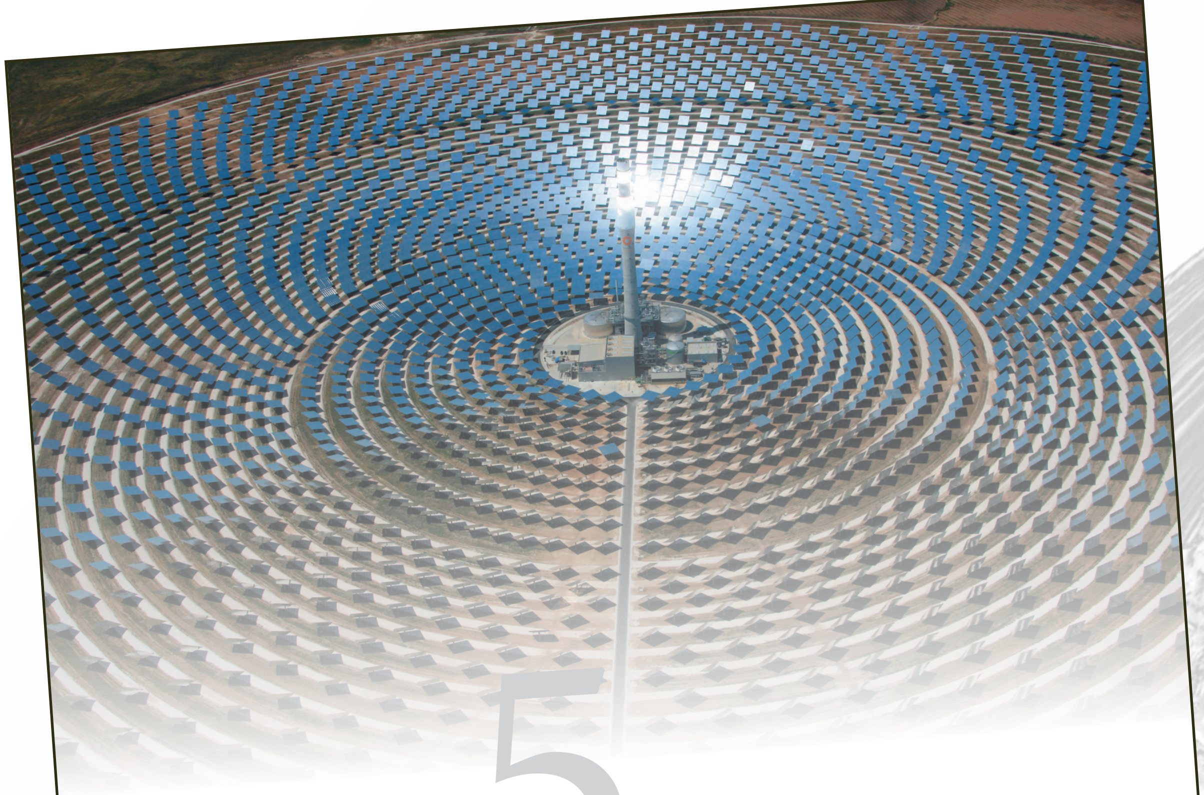


5 Energy

CONCEPTS

QUANTITATIVE TOOLS

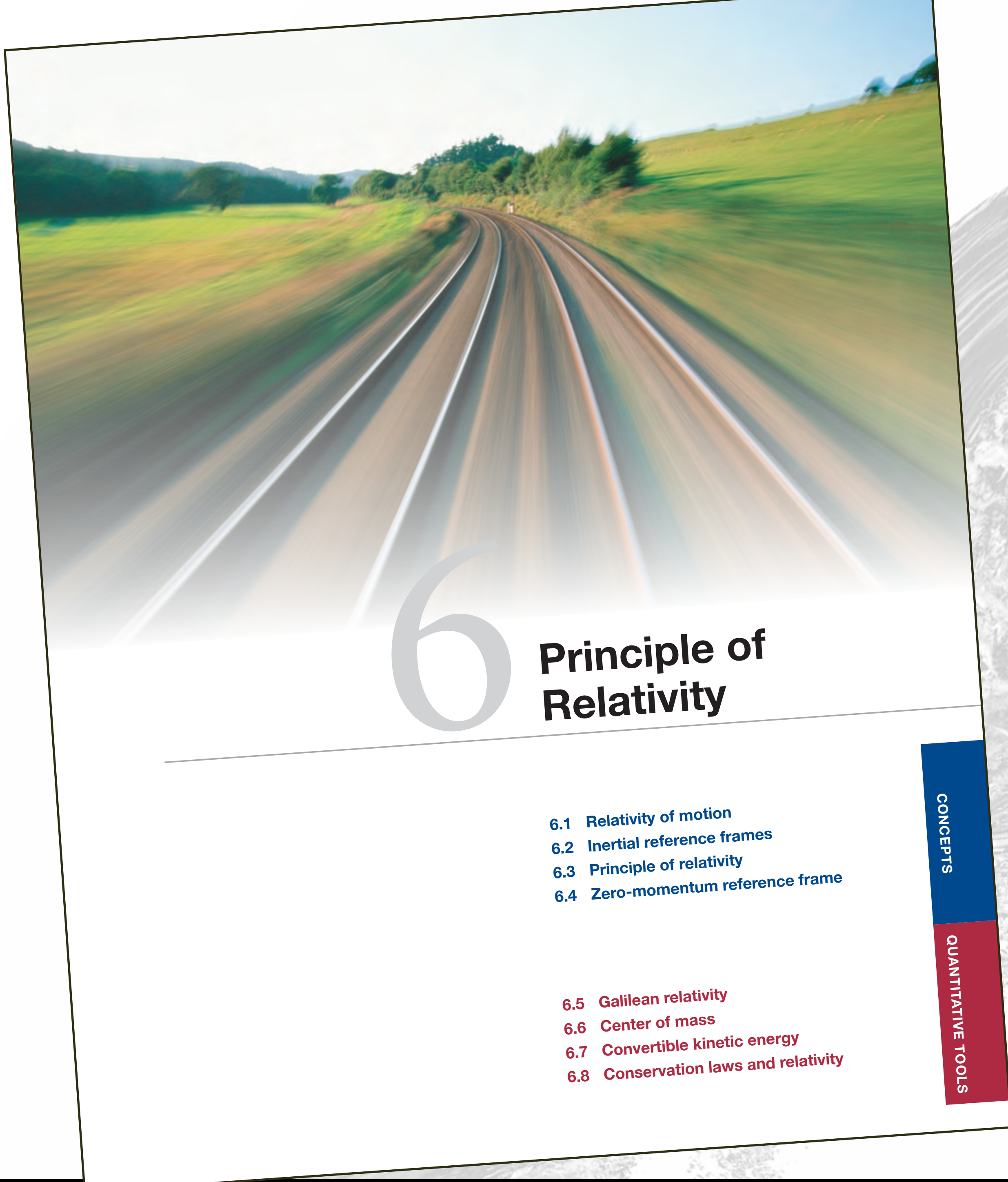
1 architecture

2 content

elastic vs. inelastic

1 architecture

2 content

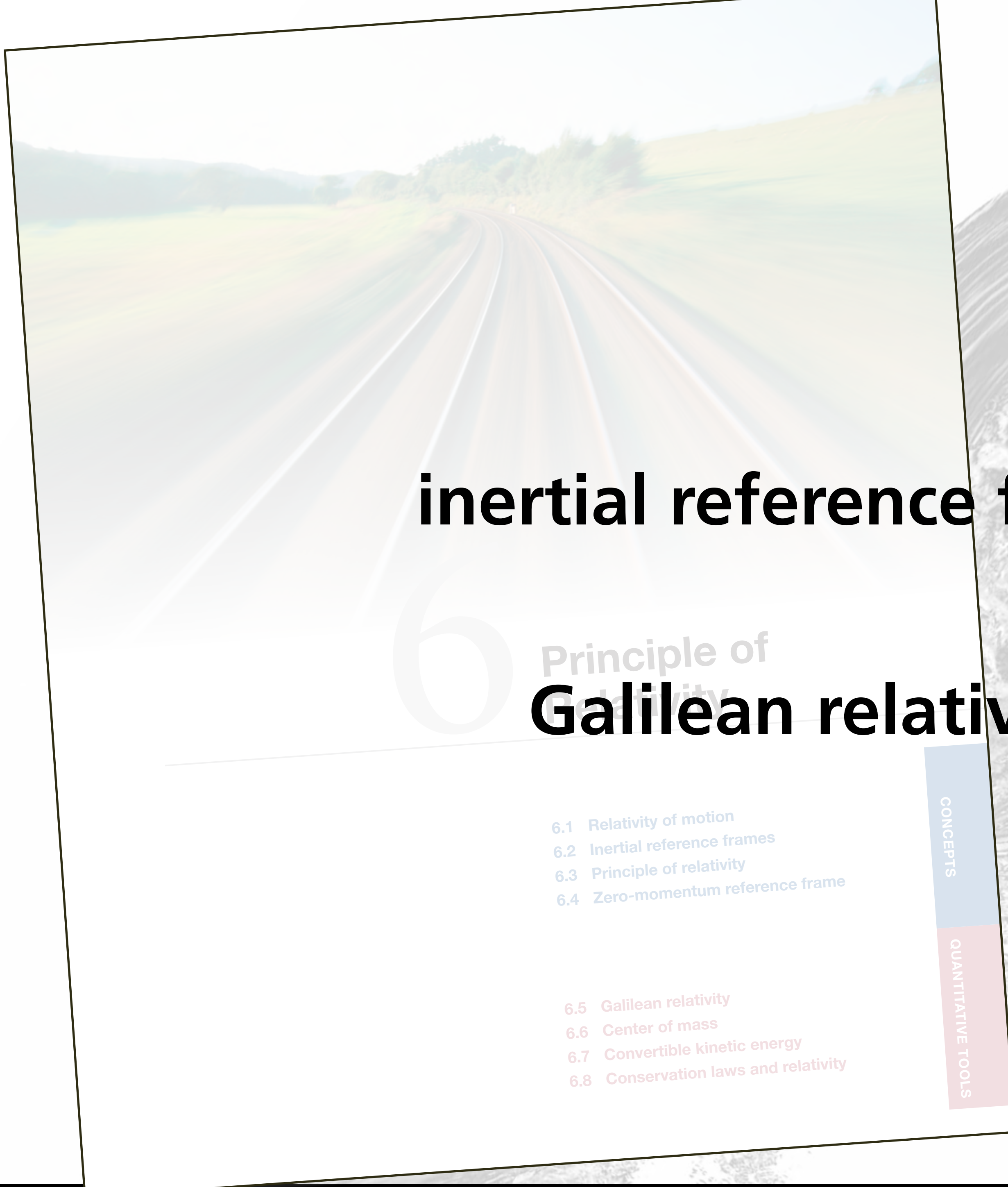

6 Principle of Relativity

CONCEPTS

QUANTITATIVE TOOLS

1 architecture

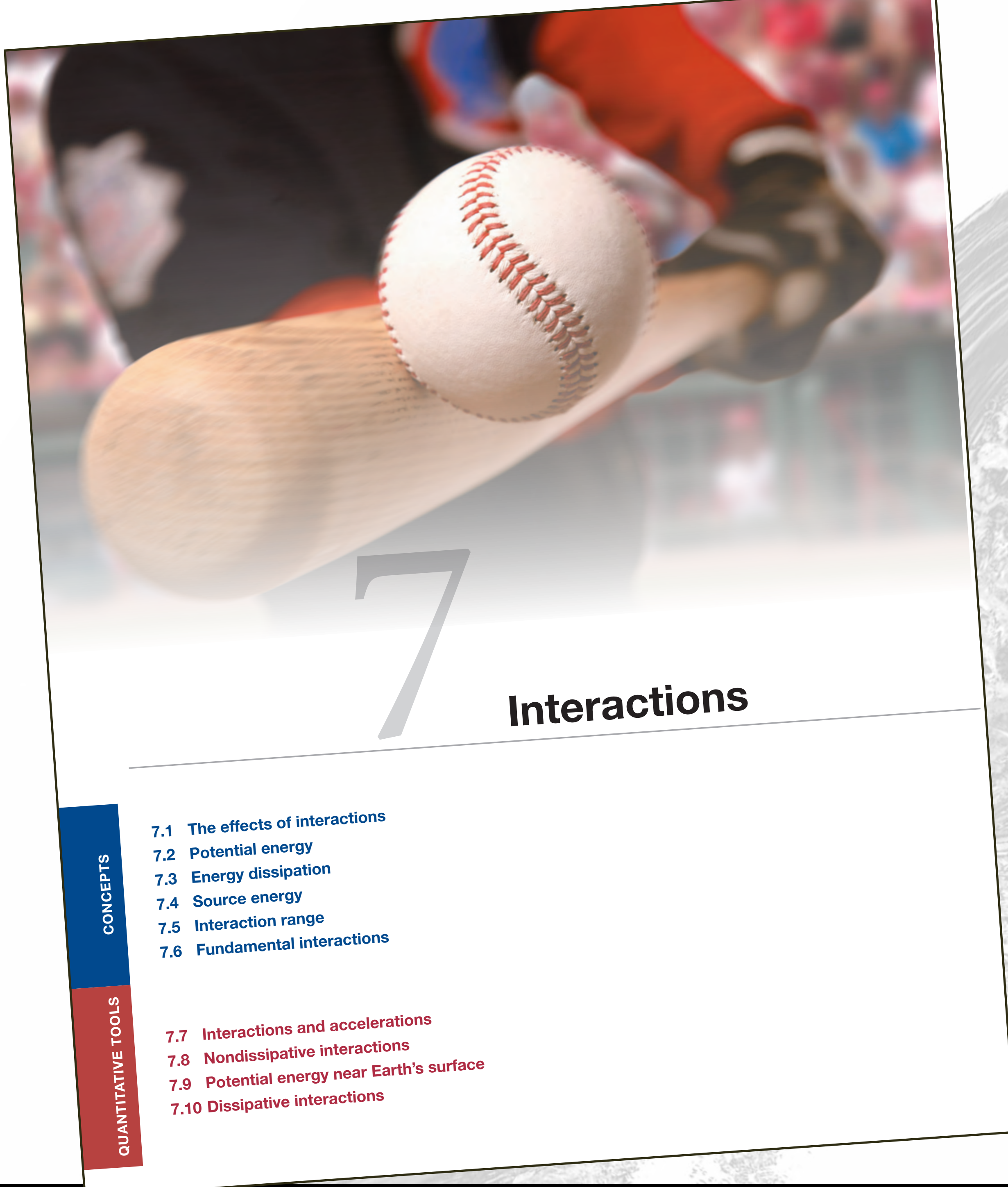
2 content



inertial reference frames

Galilean relativity

1 architecture **2 content**



7 Interactions

CONCEPTS

QUANTITATIVE TOOLS

1 architecture   2 content

8 Force

CONCEPTS

QUANTITATIVE TOOLS

1 architecture

2 content


8 Force

CONCEPTS

8.1 Momentum and force
8.2 The reciprocity of forces
8.3 Identifying forces
8.4 Translational equilibrium
8.5 Free-body diagrams
8.6 Springs and tension

QUANTITATIVE TOOLS

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

$$\sum \vec{F} \equiv \frac{d\vec{p}}{dt}$$

1 architecture

2 content

9 Work

CONCEPTS

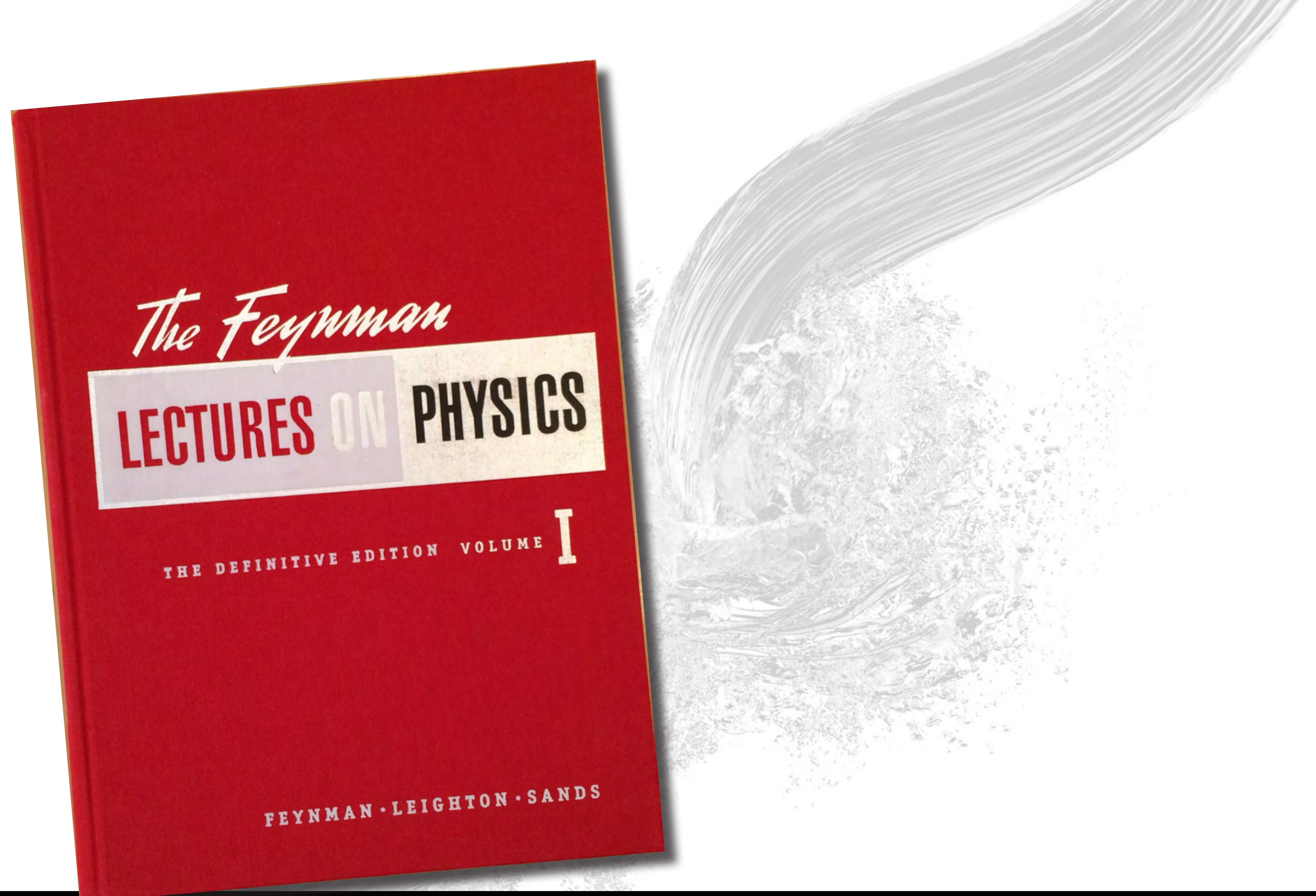
QUANTITATIVE TOOLS

1 architecture

2 content

how much work is it to switch?

1. architecture
2. content



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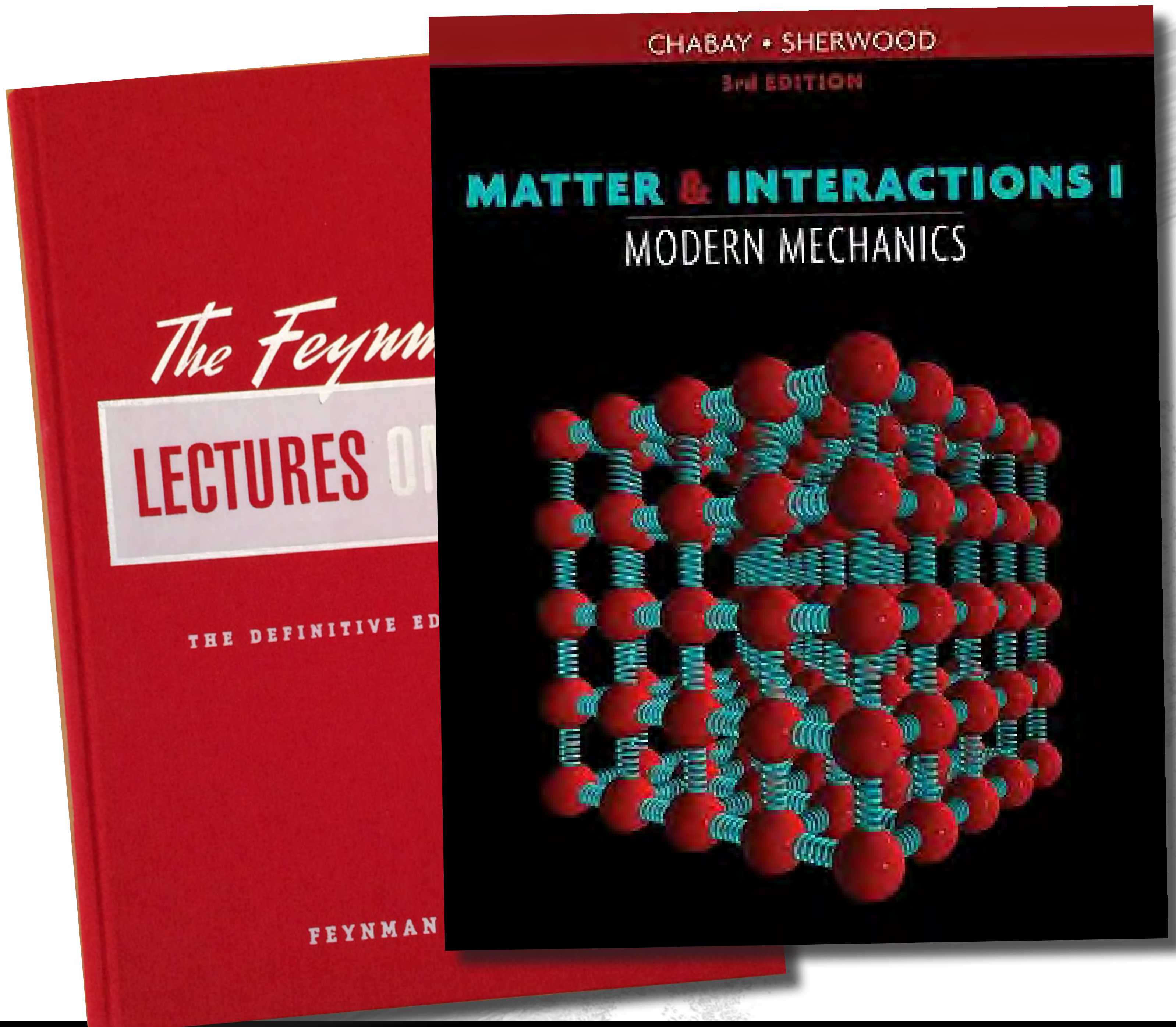

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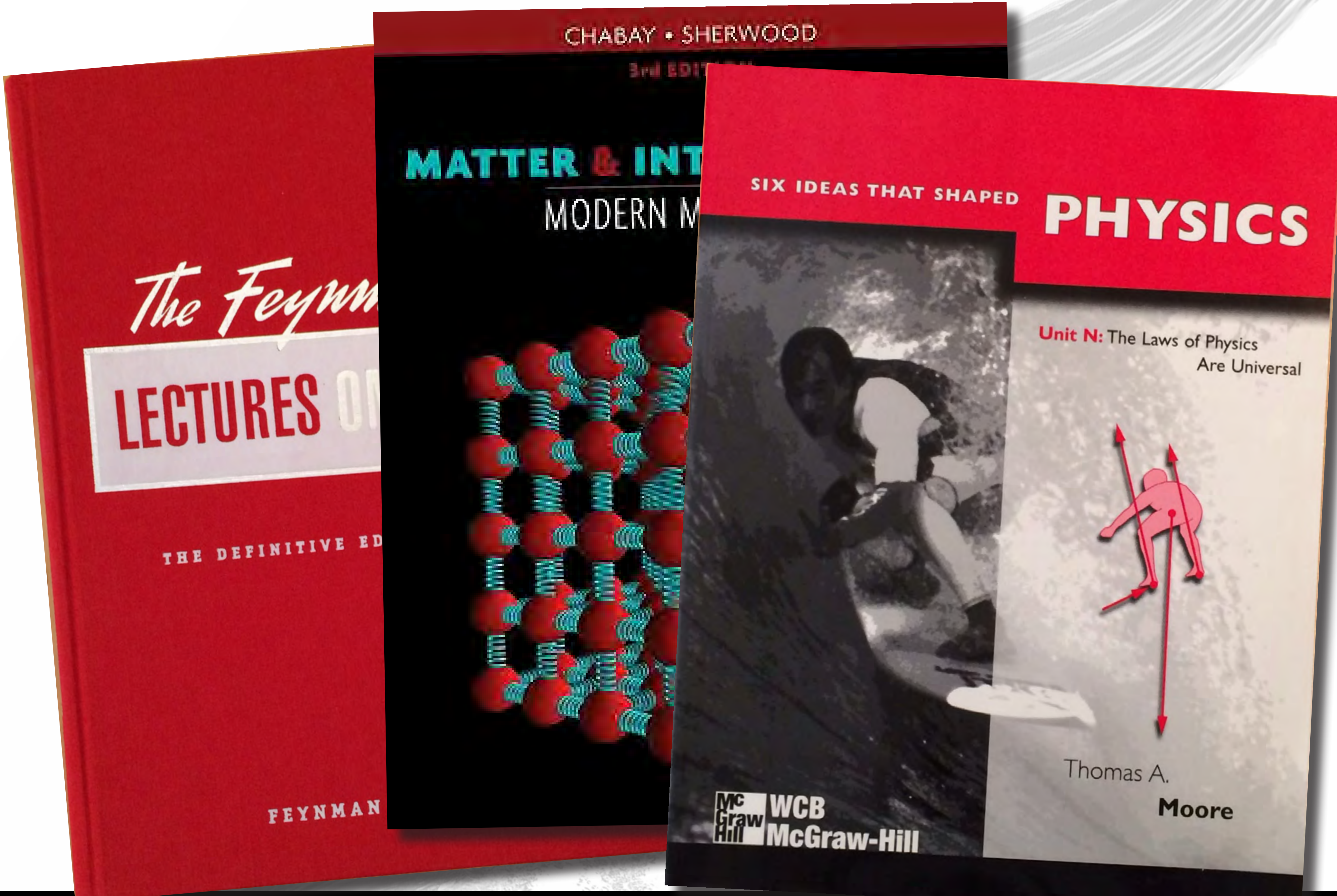

1 architecture

2 content

Traditional	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
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

1 architecture 2 content

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

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1D

3D

1 architecture

2 content

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1D

3D

1 architecture

2 content

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1D

3D

1 architecture 2 content

Traditional	Principles and Practice	
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2. Motion in one dimension	2. Motion in one dimension	
3. Vectors	3. Acceleration	
4. Motion in two dimensions	4. Momentum	conservation
5. The laws of motion	5. Energy	conservation
6. Circular motion	6. Principle of relativity	conservation
7. Work and kinetic energy	7. Interactions	conservation
8. Potential energy and CoE	8. Force	dynamics
9. Momentum and collisions	9. Work	dynamics
10. Rotation about a fixed axis	10. Motion in a plane	
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rotation

1 architecture

2 content

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periodic

1 architecture

2 content

mostly minor rearrangements!

easily custom tailored

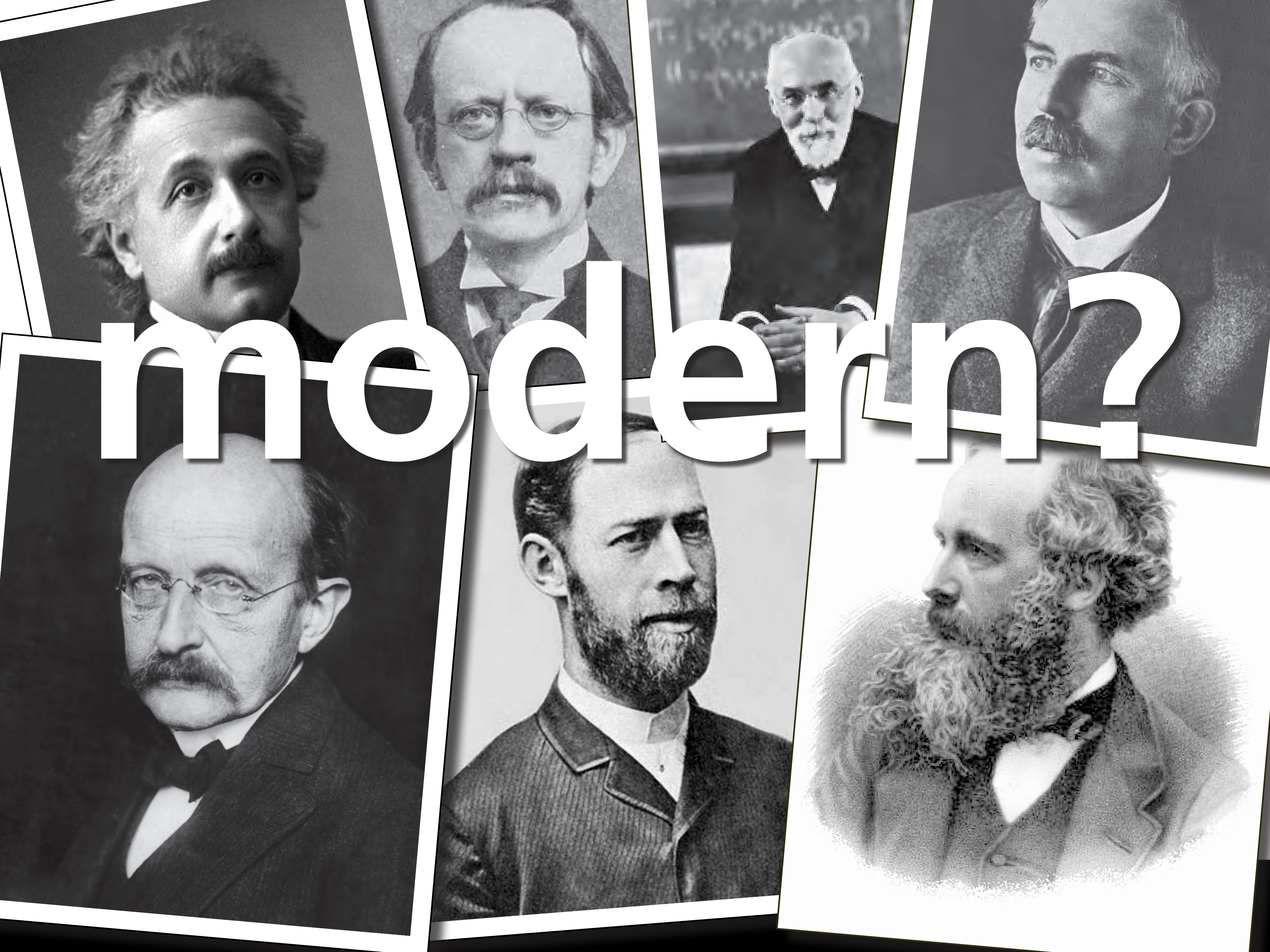
Table 1 Scheduling matrix

Topic	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

1 architecture 2 content

where is modern physics?

❶ architecture ❷ content


modern?

where is modern physics?

ALL physics is modern!

conservation as modern foundation

1. Foundatio
2. Motion in one
3. Acceleration
4. Momentum
5. Energy
6. Principle of relativity
7. Interactions
8. Force
9. Work
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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

universality;
particle
interactions

1. Foundatio
2. Motion i
3. Accelera
4. Momentu
5. Energy
6. Principle of rel vity
7. Interactions
8. Force
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concepts of general relativity

1 architecture

2 content

1. Foundations
2. Motion in one dimension
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4. Momentum
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**S.R.
as part of
mechanics**

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5. Energy
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7. Interactions
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statistical foundation for thermo

1 architecture 2 content

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31. Electric circuits
32. Electronics
33. Ray optics
34. Wave and particle optics

relativistic
E&M
connection

1 architecture
2 content

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27. Magnetic…
28. Magnetic… …otion
29. Changing m…
30. Changing elect…
31. Electric circuits
32. Electronics
33. Ray optics
34. Wave and particle optics

semiconductors
transistors
logic gates

1 architecture

2 content

1. Foundations
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28. Magnetic fi … motion
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30. Changing
31. Electric circ
32. Electronics
33. Ray optics
34. Wave and particle optics

photons & particle interference

1 architecture

2 content

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 problem-solving 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

...presentation of physics begins by defining it and its scope of the study of "all there is in the ... the skills developed in studying physics to other aspects of life also is ... The chapter launches with a discussion of the ... often taught in grade school.

1 architecture

2 content

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

1 architecture

2 content

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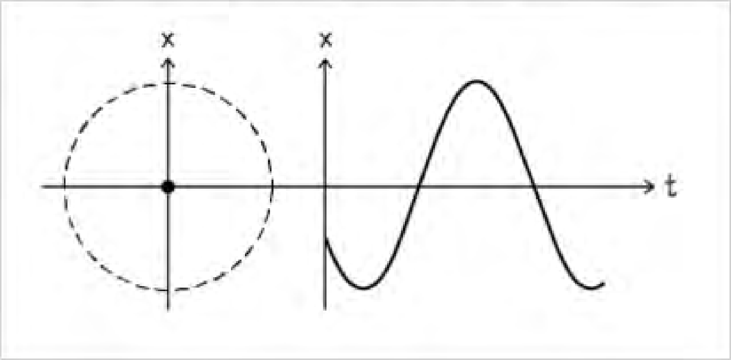
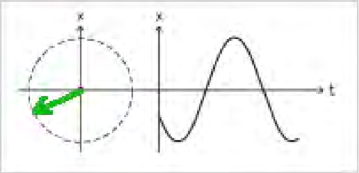
Jump to 1 2 3 4 5 6 7 8 9 10

3. direction

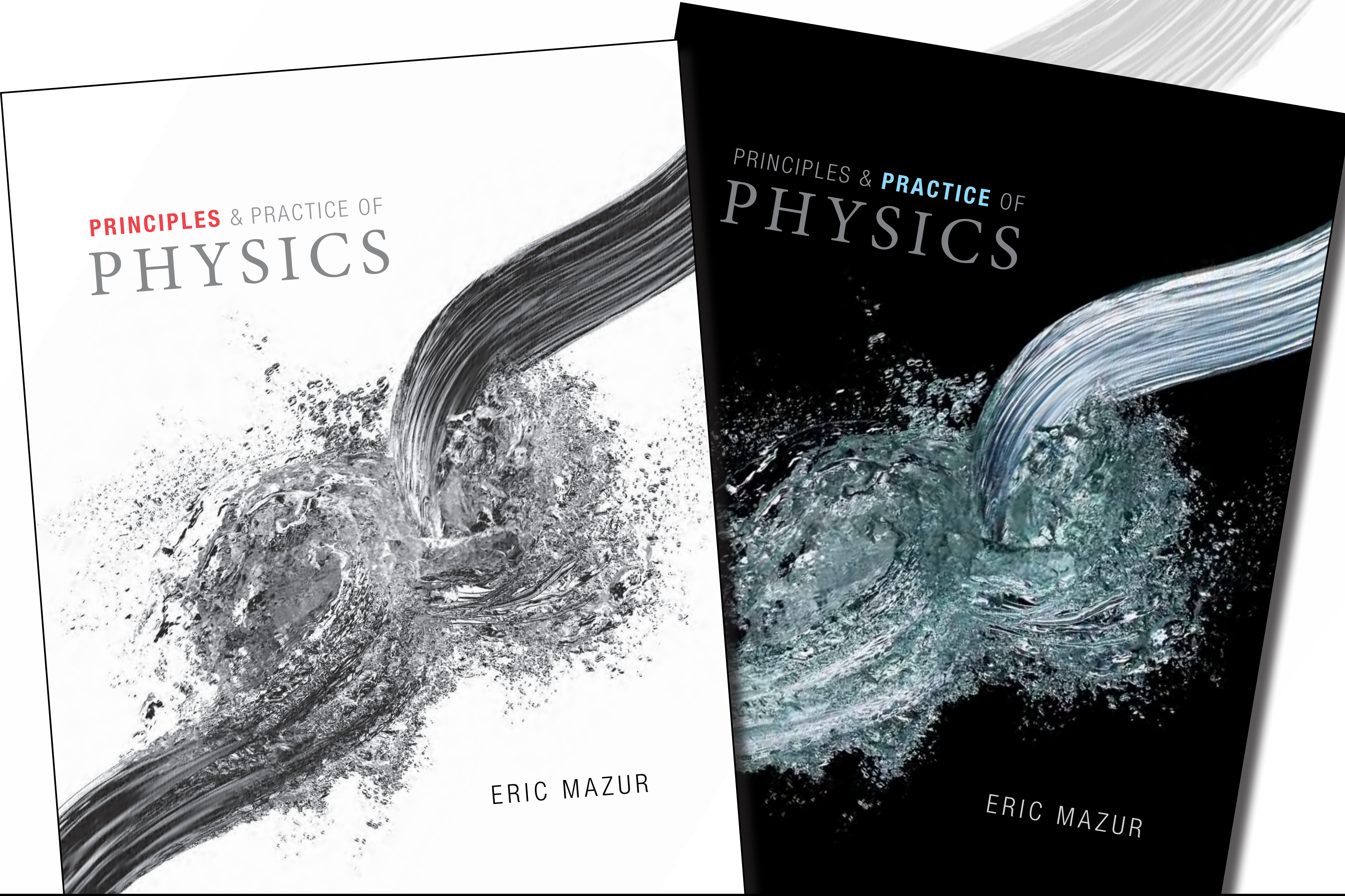
In the reference circle on the left, draw a phasor representing the oscillation shown on the right.



Answer



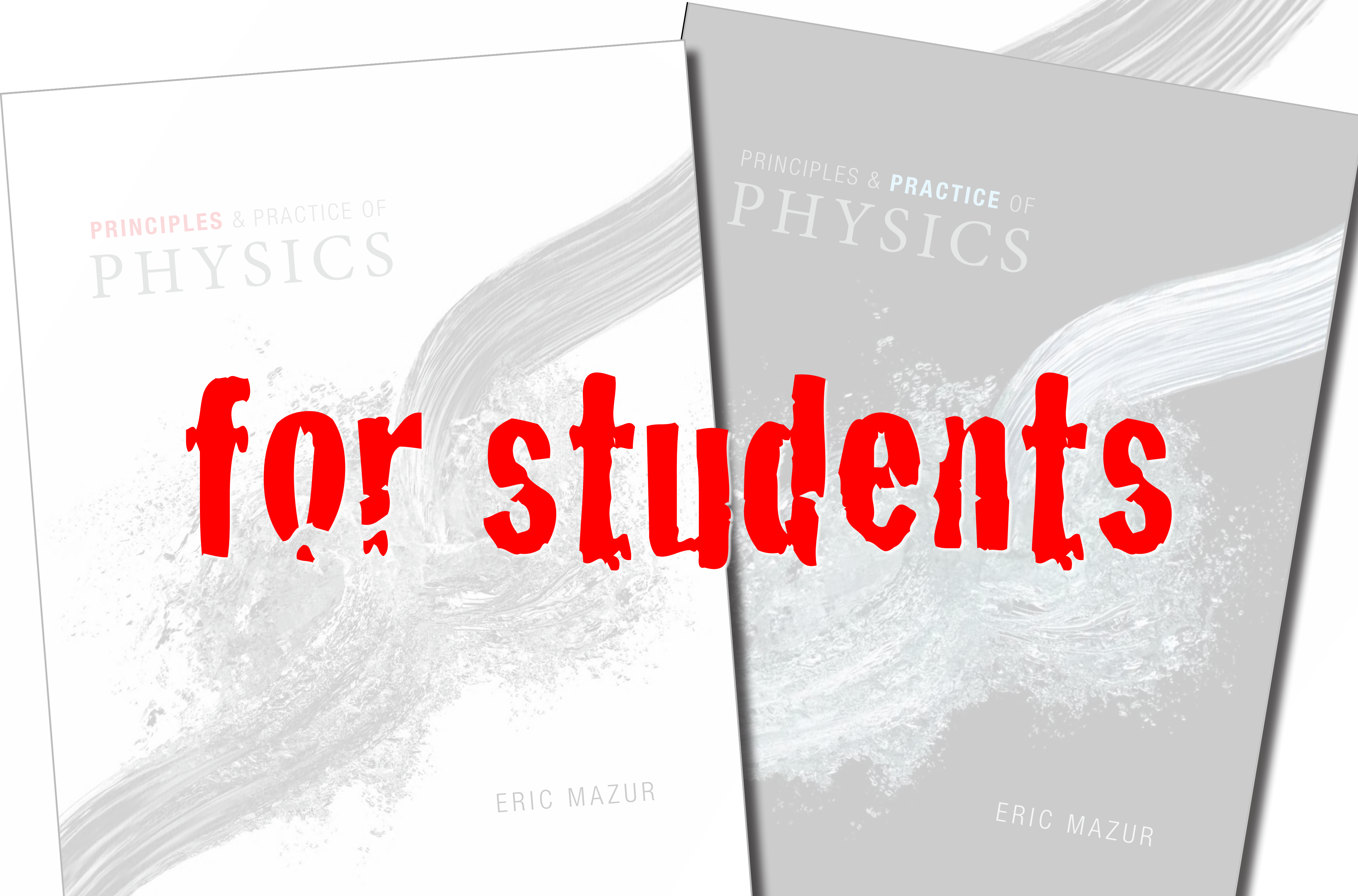
1 architecture 2 content



1 architecture

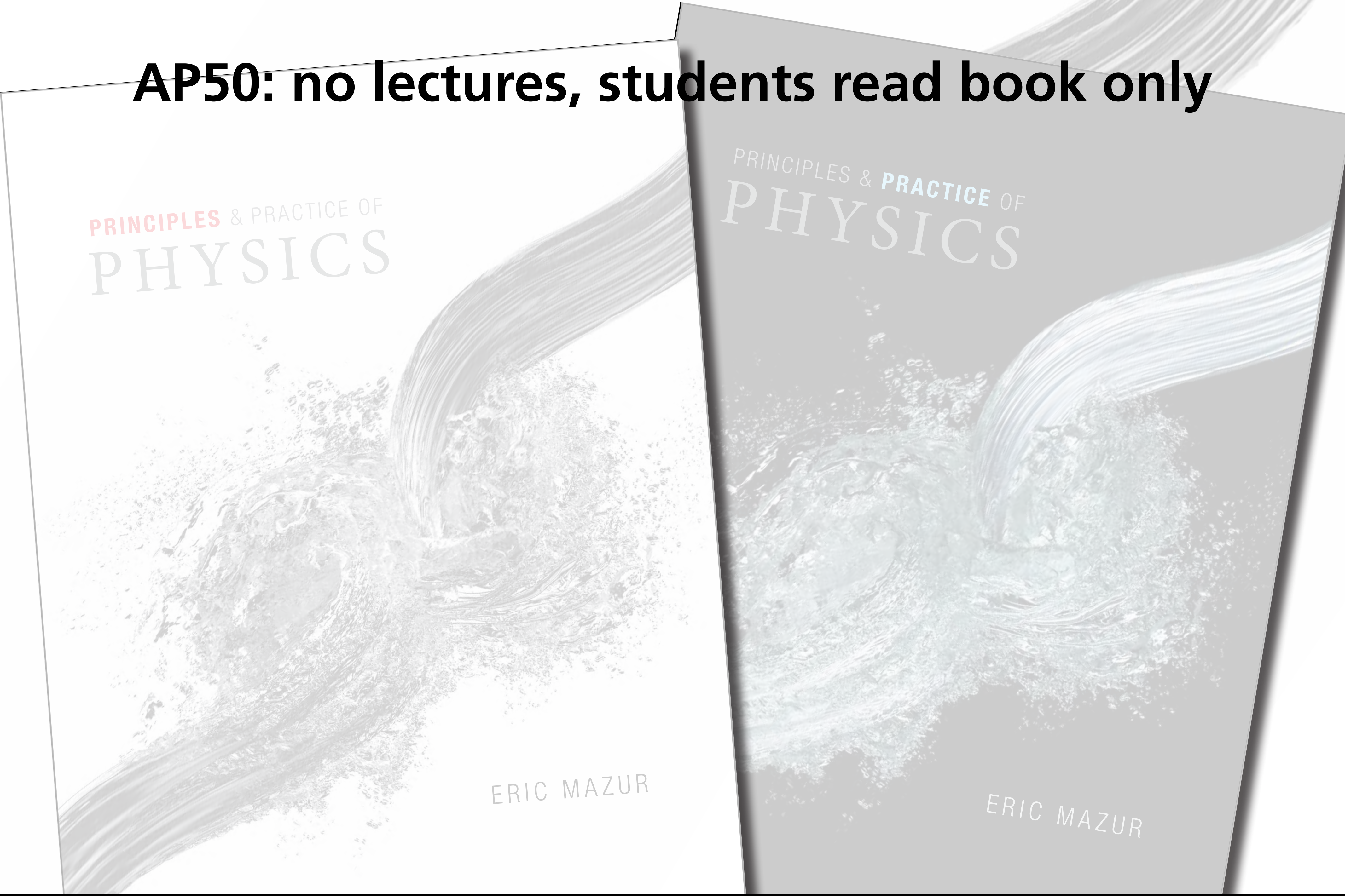
2 content

3 results



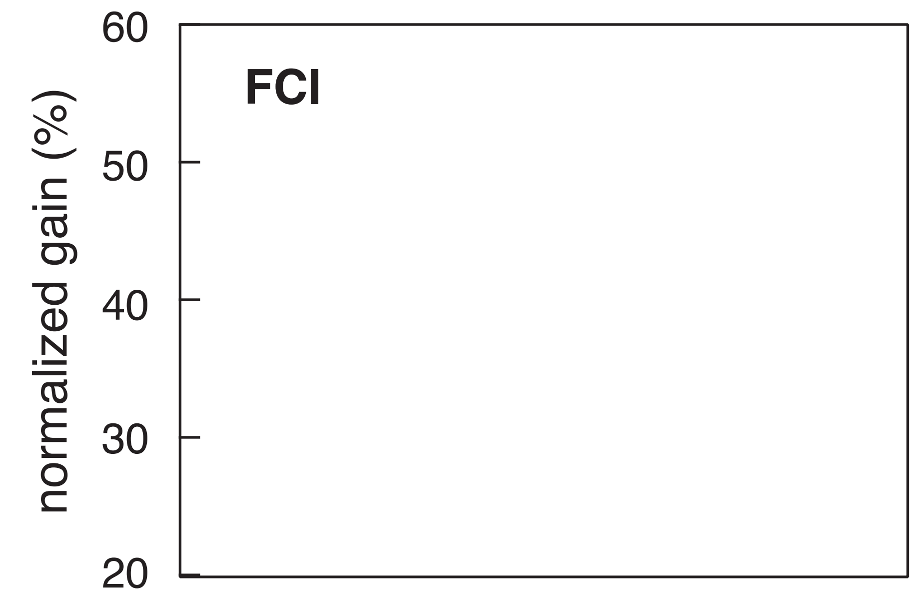
1 architecture 2 content 3 results

AP50: no lectures, students read book only



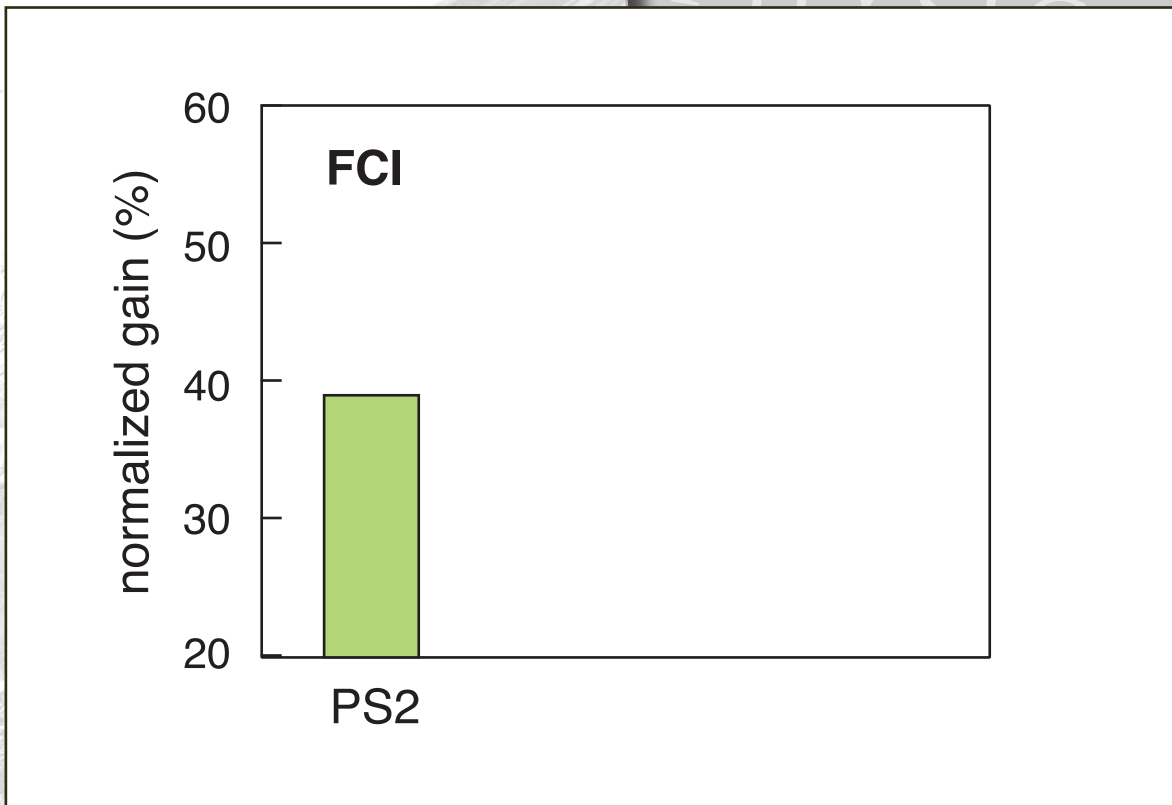
1 architecture 2 content 3 results

AP50: no lectures, students read book only



1 architecture 2 content 3 results

AP50: no lectures, students read book only



1 architecture 2 content 3 results

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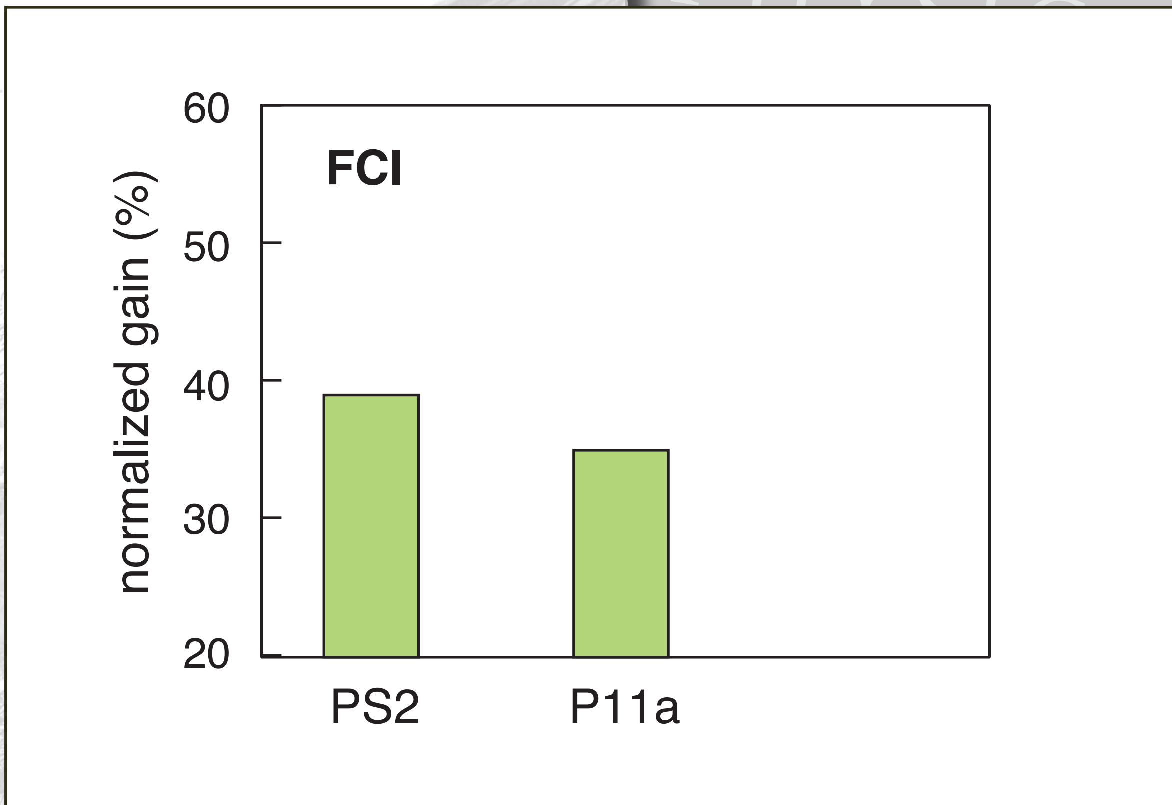
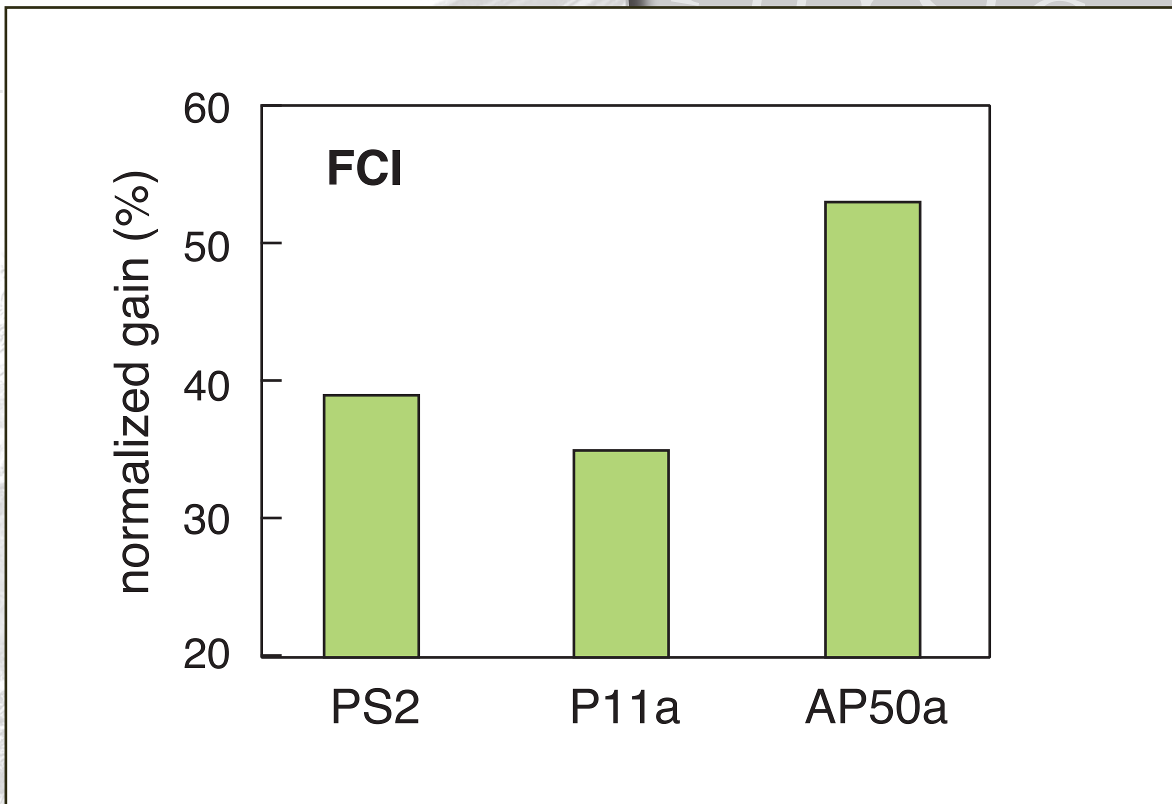


❶ architecture ❷ content ❸ results

AP50: no lectures, students read book only

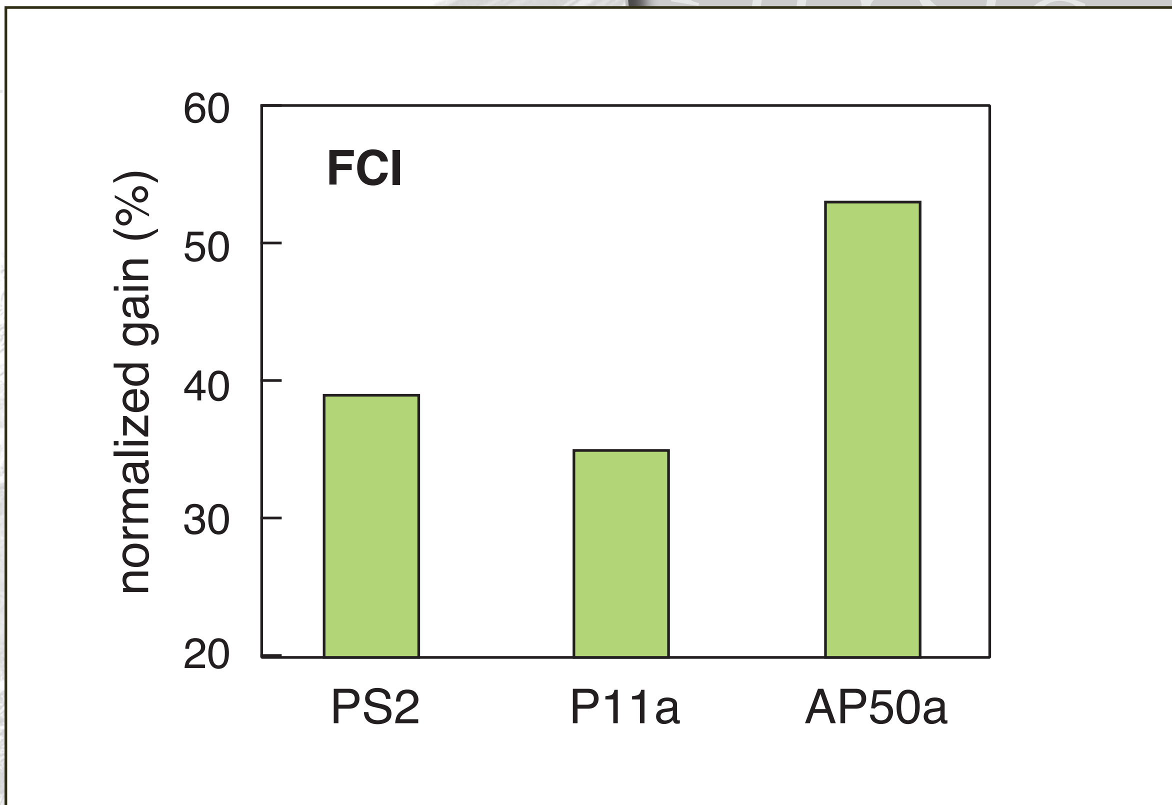


1 architecture

2 content

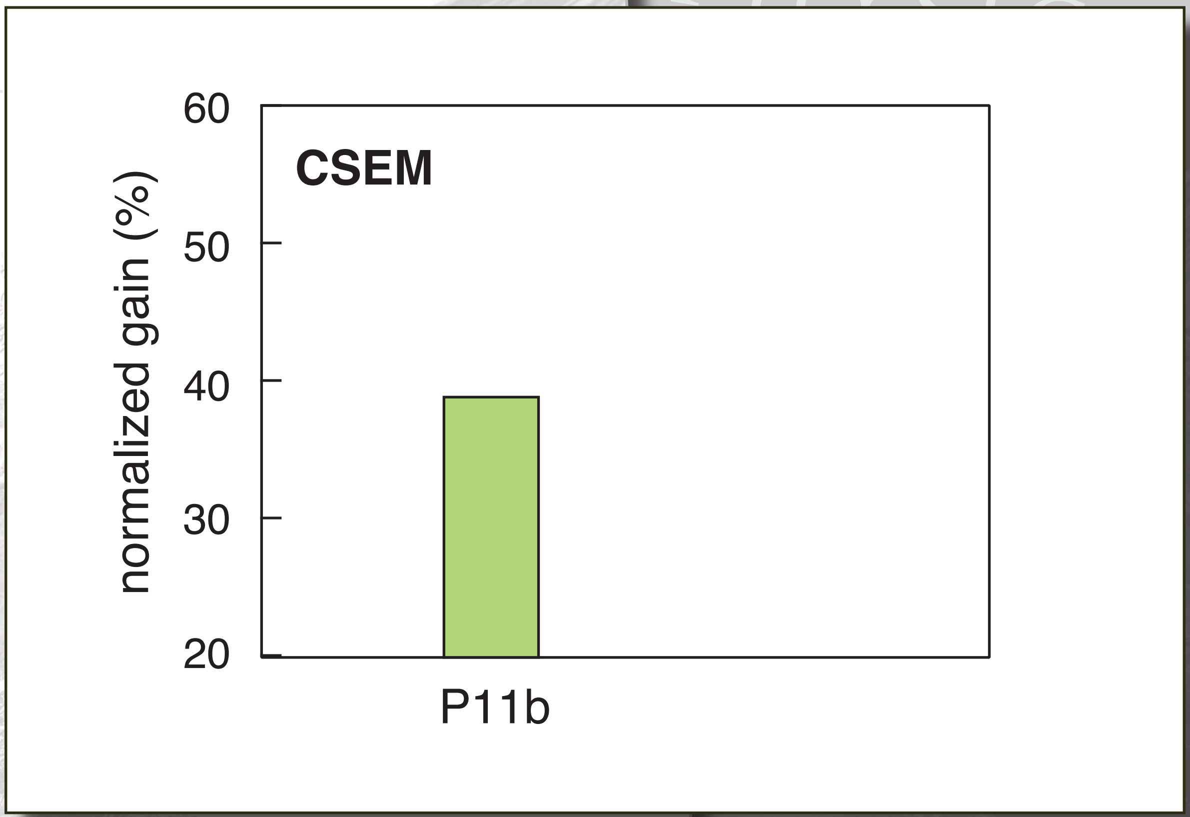
3 results

AP50: no lectures, students read book only



largest conceptual gain in *any* course past 6 yrs!

AP50: no lectures, students read book only



1 architecture
2 content
3 results

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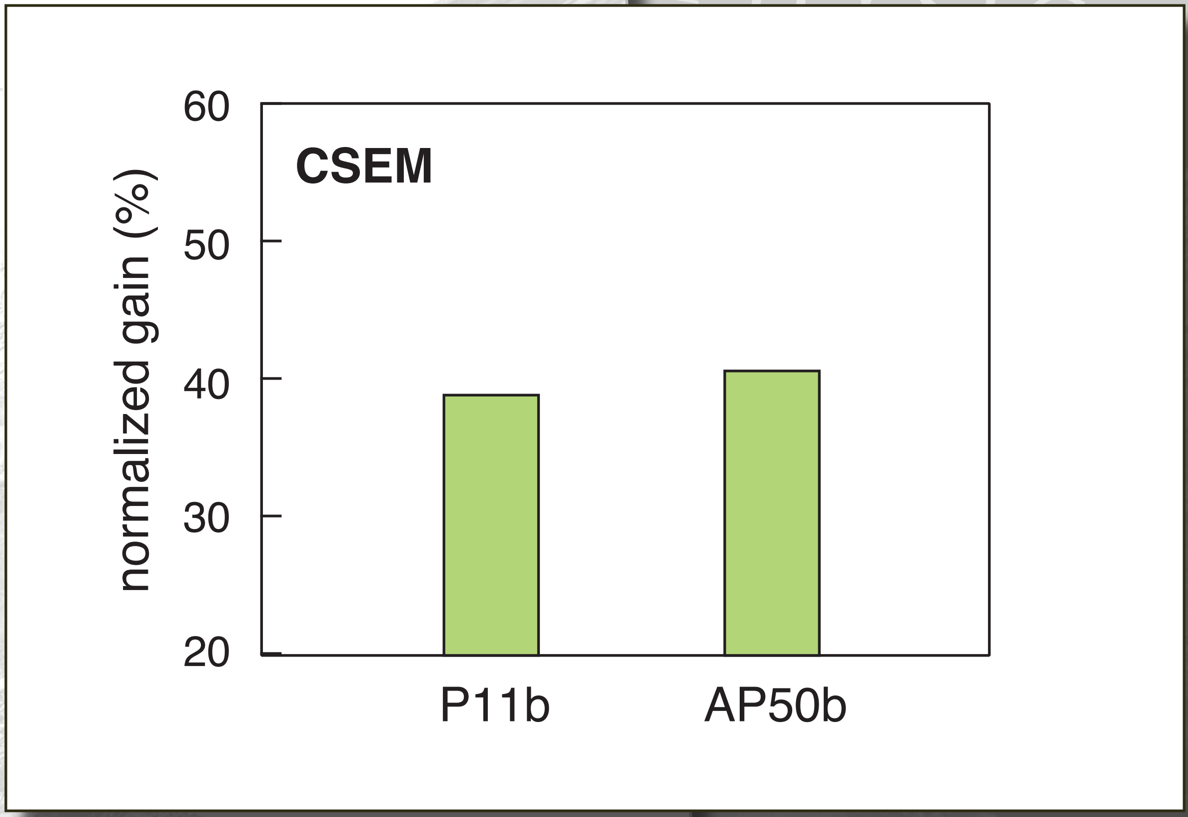
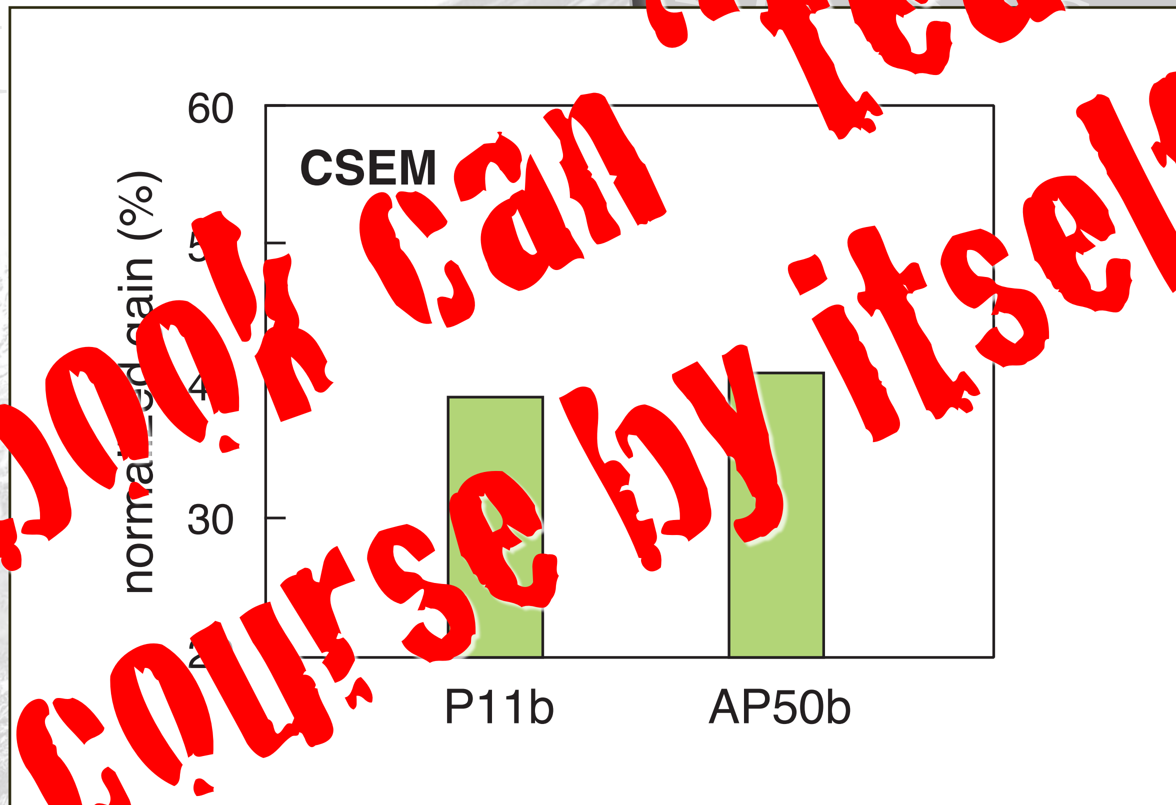


as good as when I do my best teaching!

AP50: no lectures, students read book only

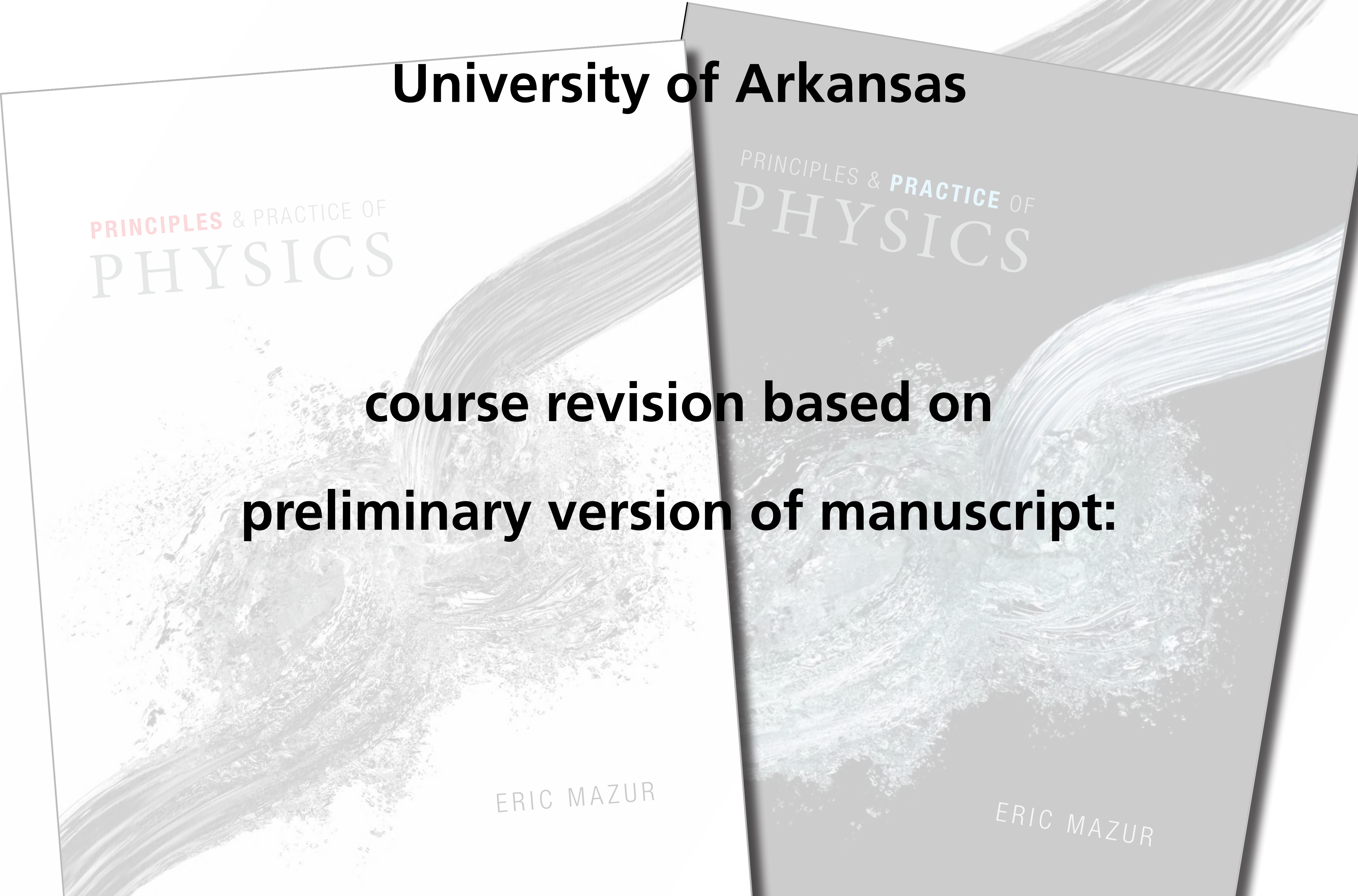


this book can "teach" the course by itself. . .

as good as when I do my best teaching!

❶ architecture ❷ content ❸ results

University of Arkansas

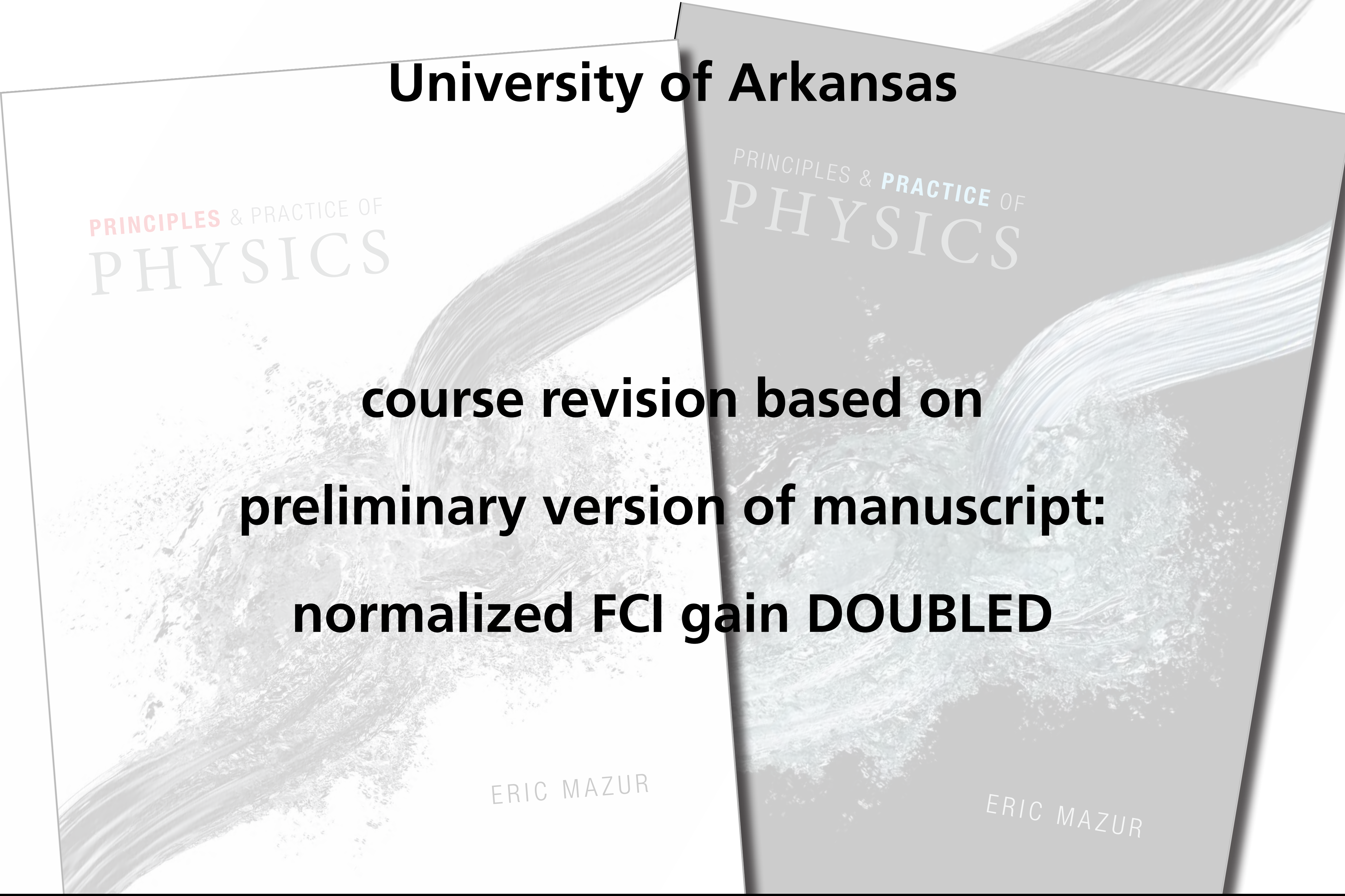


course revision based on

preliminary version of manuscript:

1 architecture　　2 content　　3 results

University of Arkansas



course revision based on

preliminary version of manuscript:

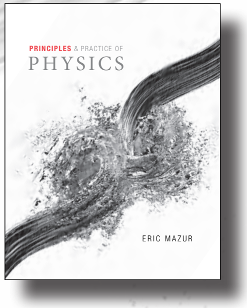
normalized FCI gain DOUBLED

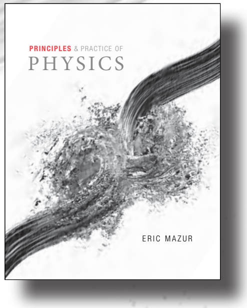
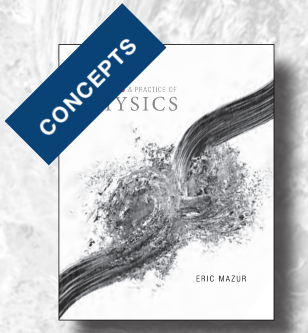
Current Adoptions

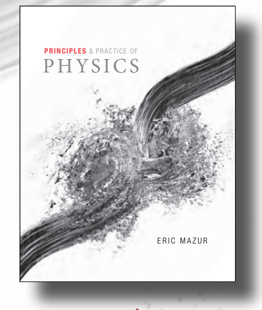
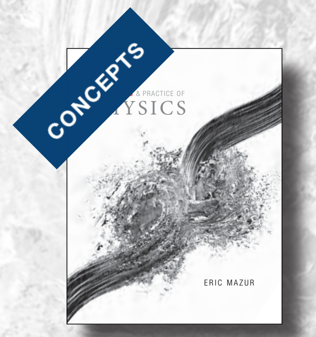
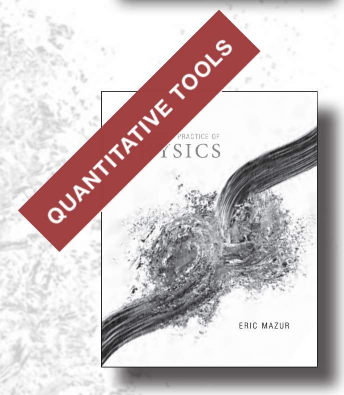
Abilene Christian University
Bellingham Technical College
Bethany Lutheran College
Chaffey College
Eastfield College
Embry-Riddle Aera Universit–Prescott
Evergreen State College
Florida State University
Gallaudet University
Gogebic Community College
Harvard University
Highline Community College
Hope 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
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

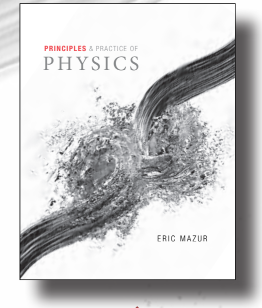
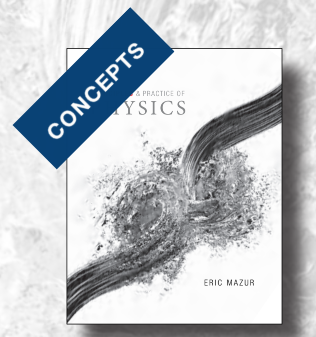
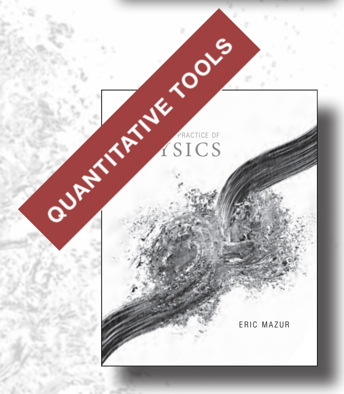
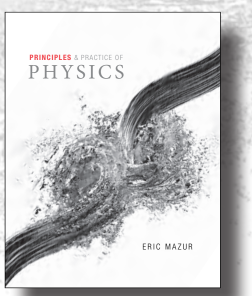
John Abbott College (Canada)
Helsinki University (Finland)
McMaster University (Canada)
Monash University (Australia)
Mount Saint Vincent University (Canada)
University of British Columbia (Canada)
University of Toronto (Canada)
University of Waterloo (Canada, 2016)

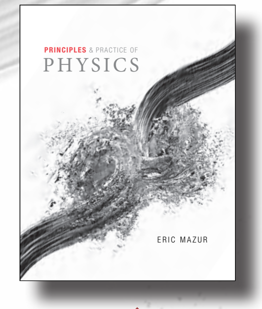
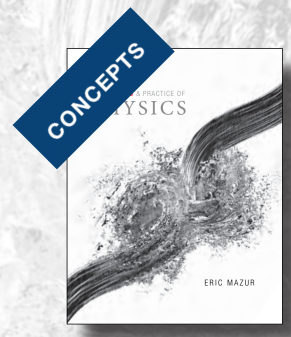
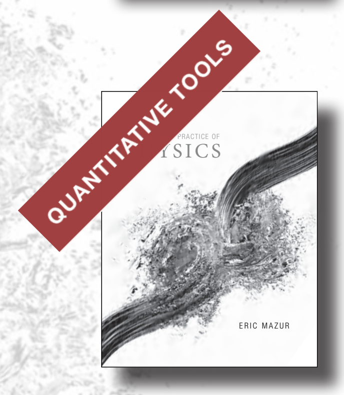
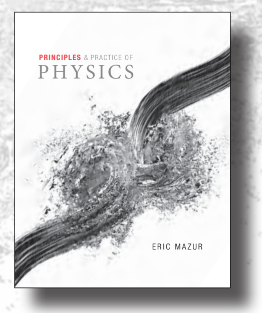
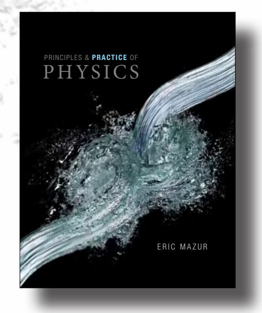
1 architecture 2 content 3 results

approach	before class	in class
traditional	–	

approach	before class	in class
traditional	–	
partially flipped		

approach	before class	in class
traditional	–	
partially flipped		

approach	before class	in class
traditional	–	
partially flipped		
fully flipped		

approach	before class	in class
traditional	–	
partially flipped		
fully flipped		

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