Teaching and Learning Physics in the 21st Century

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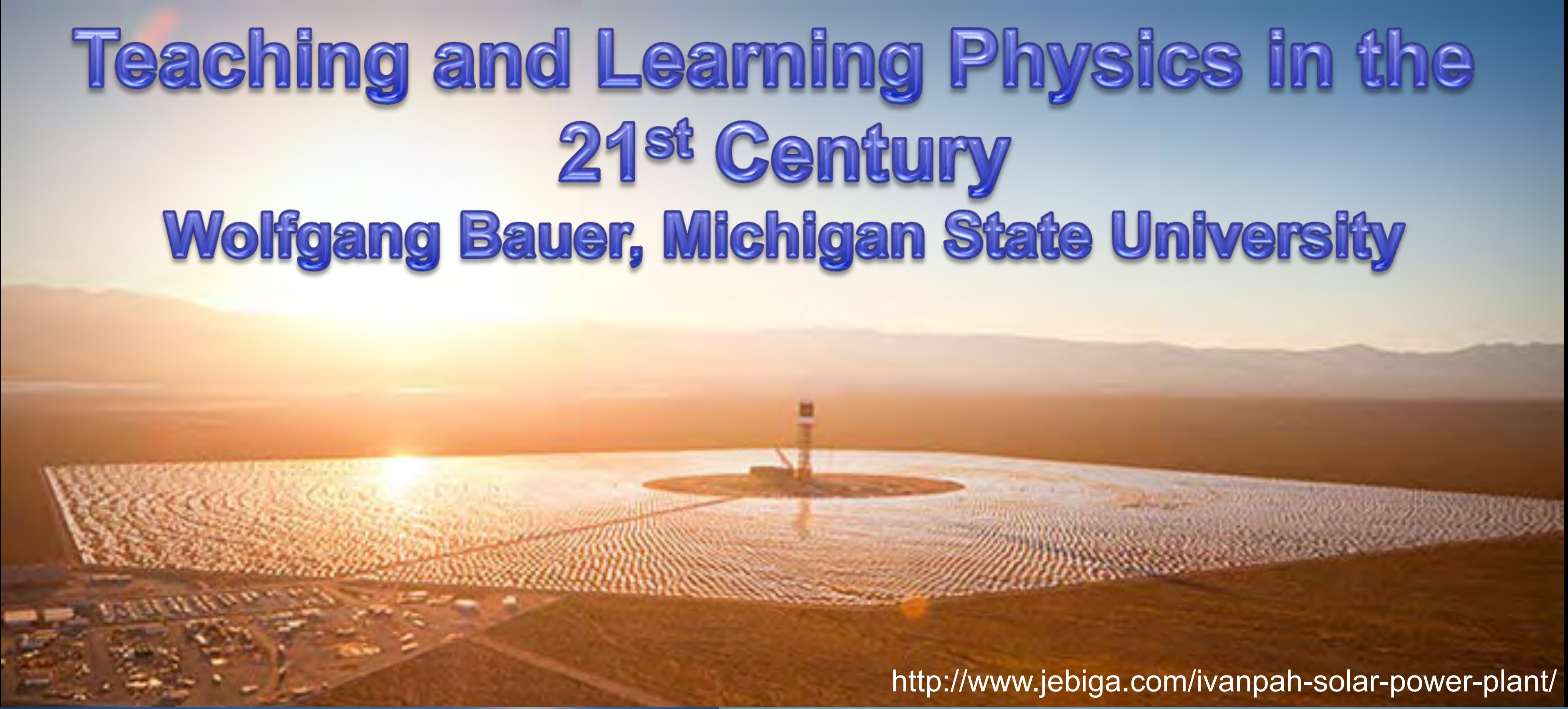

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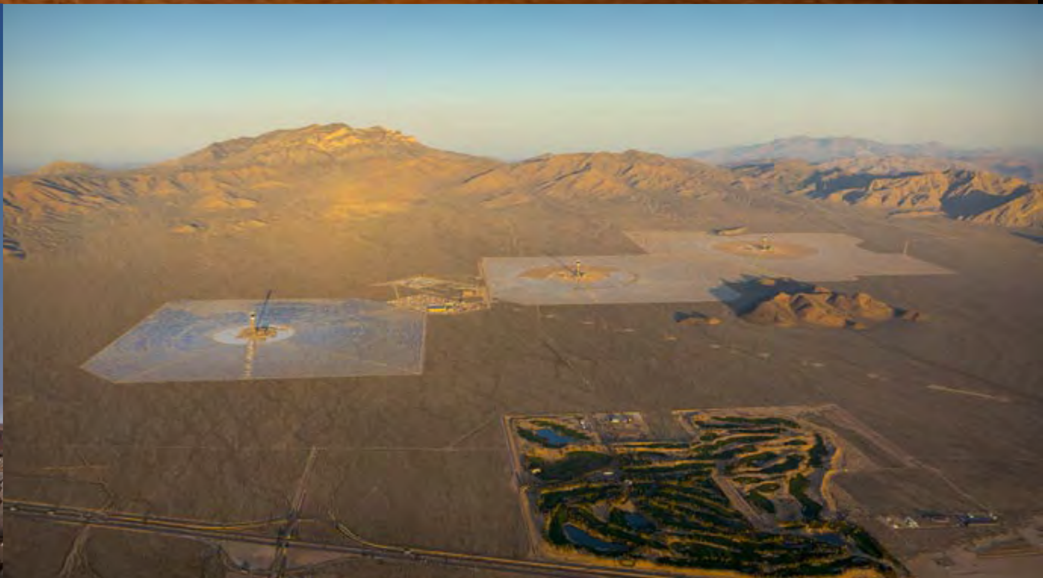
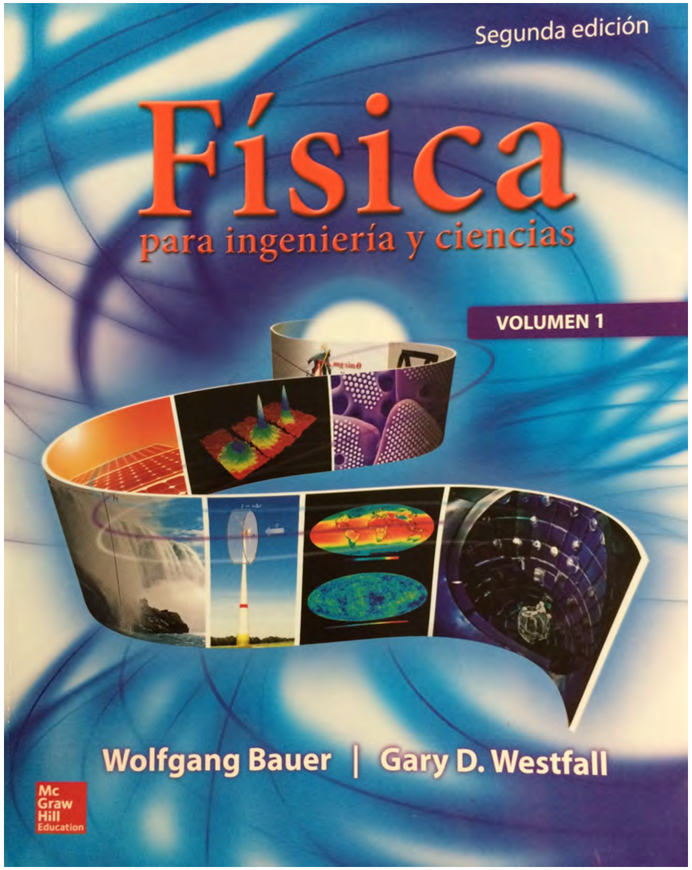


Common View

- Biology is the Science of the 21st Century
  - Chemistry dominated the 20th century
  - Physics was preeminent in the 19th century and before (from Newton to Faraday)
- Conventional introductory physics lectures help to cement this view, concentrating on Newtonian physics
- A better approach needs to include interesting recent physics topics into the 1st-year university curriculum!

Integration of Recent Research Results

- Timeliness
- Relevance
- Impact
- Accessibility to student



Energy and Power

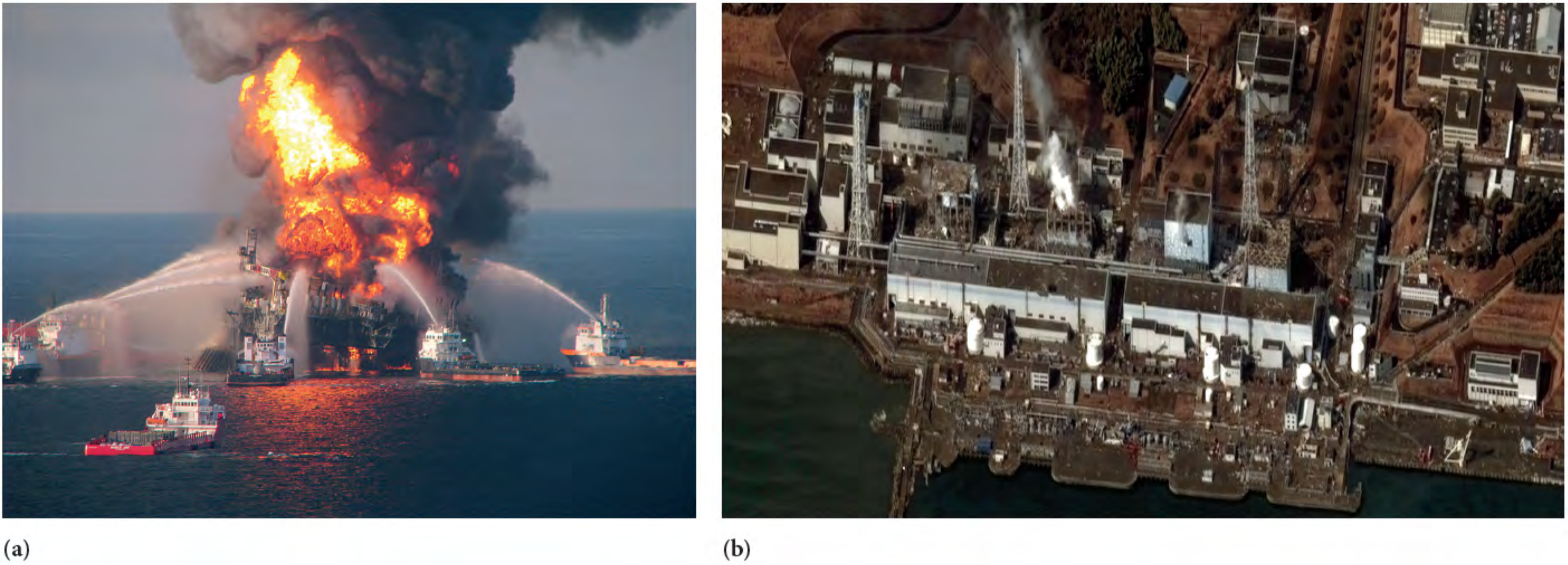


FIGURE 1 Two environmental disasters: (a) The burning Deepwater Horizon oil rig in the Gulf of Mexico, source of the biggest accidental ocean oil spill of all time. (b) The heavily damaged reactor buildings at the Fukushima Daiichi nuclear power plant, source of the largest nuclear radiation contamination to occur in the last quarter century.

FIGURE 2 An offshore wind farm between Malmö, Sweden, and Copenhagen, Denmark, that delivers a power output comparable to that of a large coal-fired power plant.

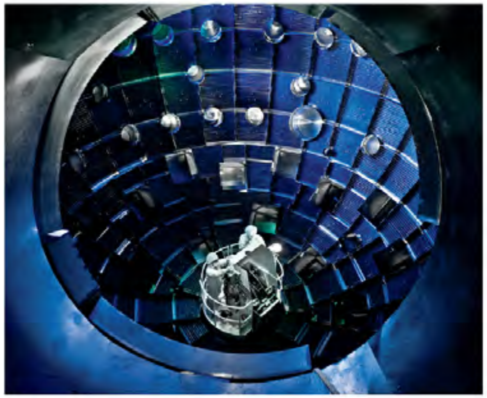


FIGURE 3 Target chamber of the National Ignition Facility, which is used to study nuclear fusion.

Condensed Matter and Quantum Physics

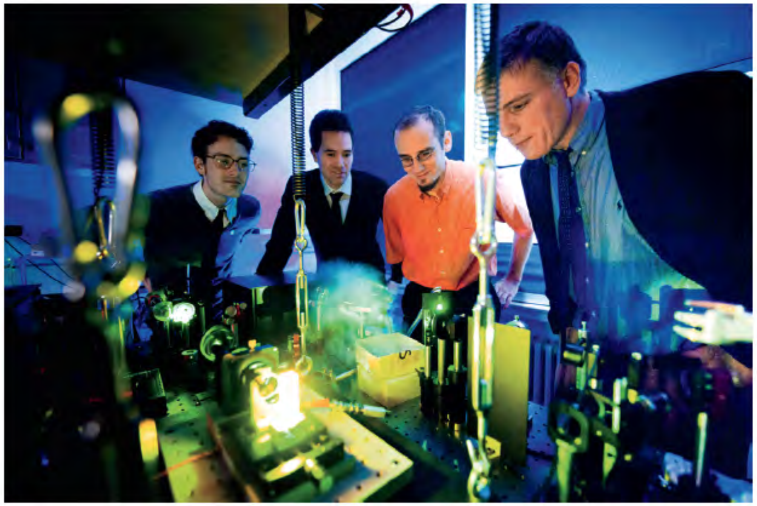


FIGURE 4 Physicists from the University of Bonn, Germany, observing their newly created "super-photons," or Bose-Einstein condensate consisting of light, which they discovered in 2010.

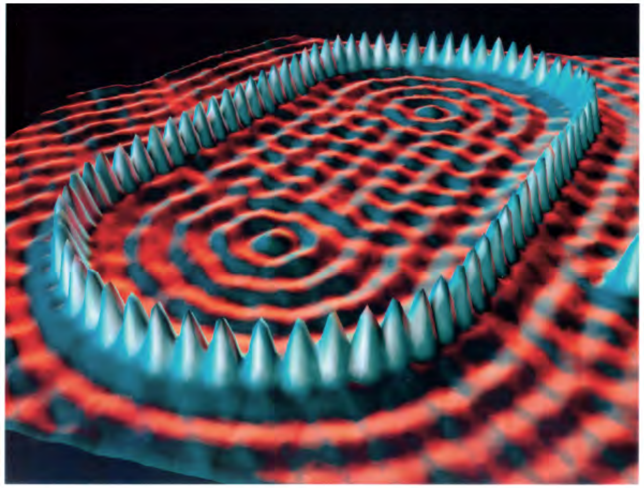


FIGURE 5 Individual iron atoms, arranged in the shape of a stadium on a copper surface. The ripples inside the "stadium" are the result of standing waves formed by electron density distributions. This arrangement was created and then imaged by using a scanning tunneling microscope (Chapter 37).

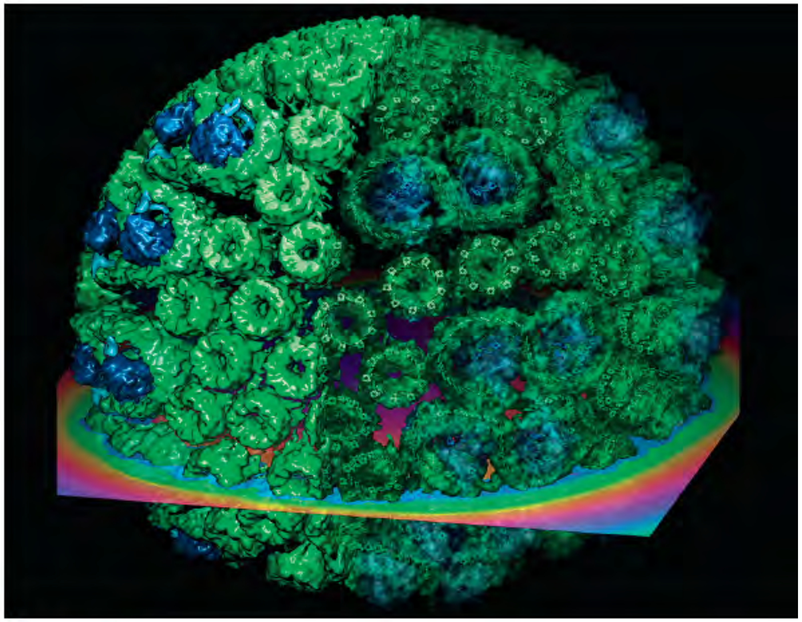


FIGURE 6 Computer simulation of the approximately 200 proteins in a chromatophore vesicle, which channels the energy of sunlight into the synthesis of adenosine triphosphate.

Astronomy and Astrophysics

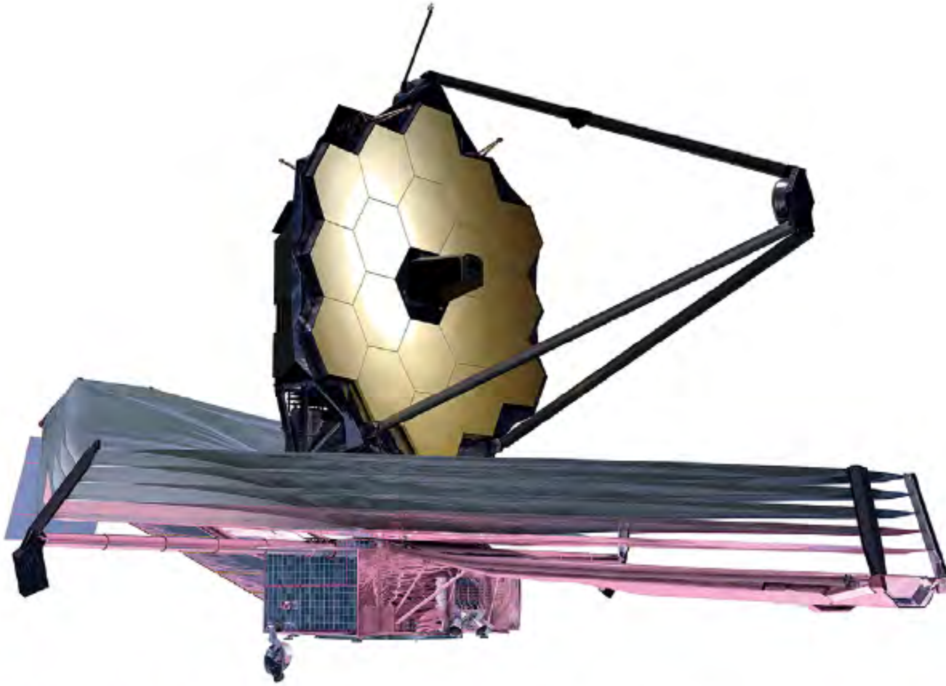


FIGURE 9 The James Webb Space Telescope.

Image from the Hubble Space Telescope

FIGURE 10 Galaxy cluster Abell 2218, with the arcs that are created by gravitational lensing due to dark matter.

The Higgs Boson

FIGURE 7 Aerial view of Geneva, Switzerland, with the location of the underground tunnel of the Large Hadron Collider superimposed in red.

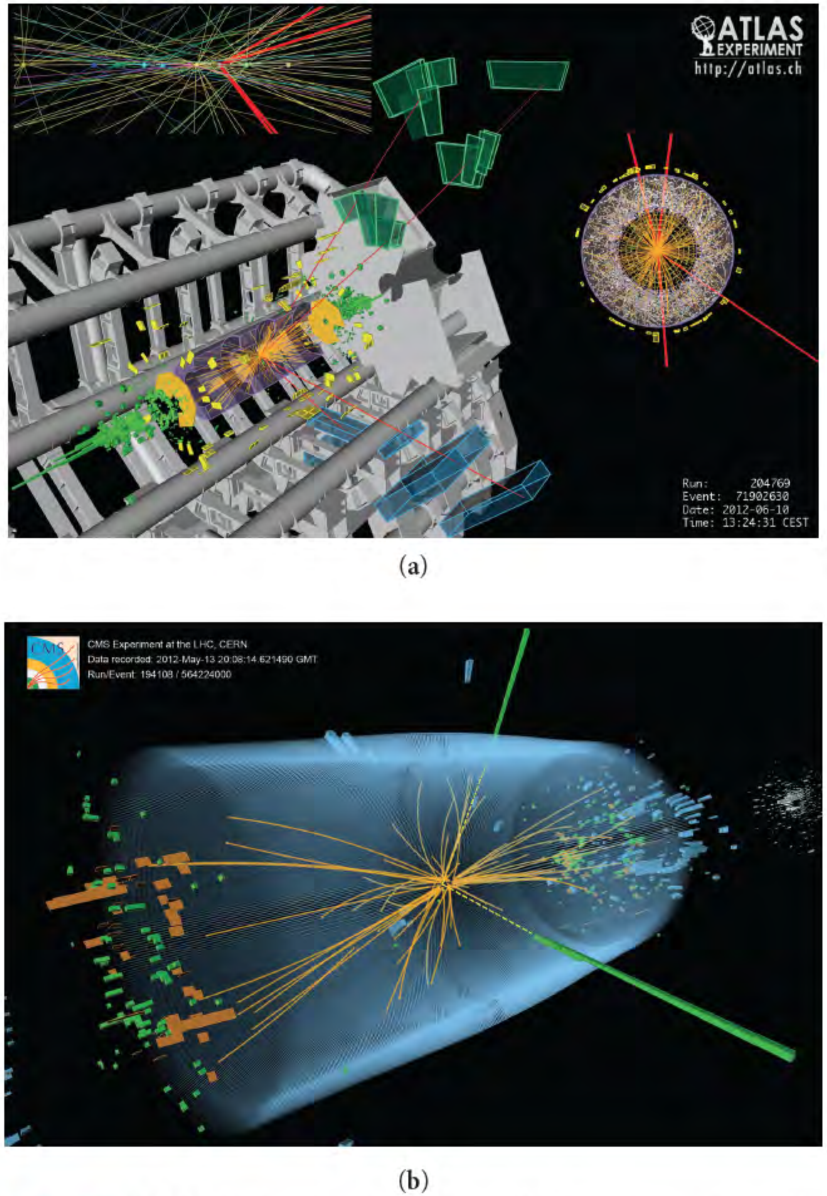
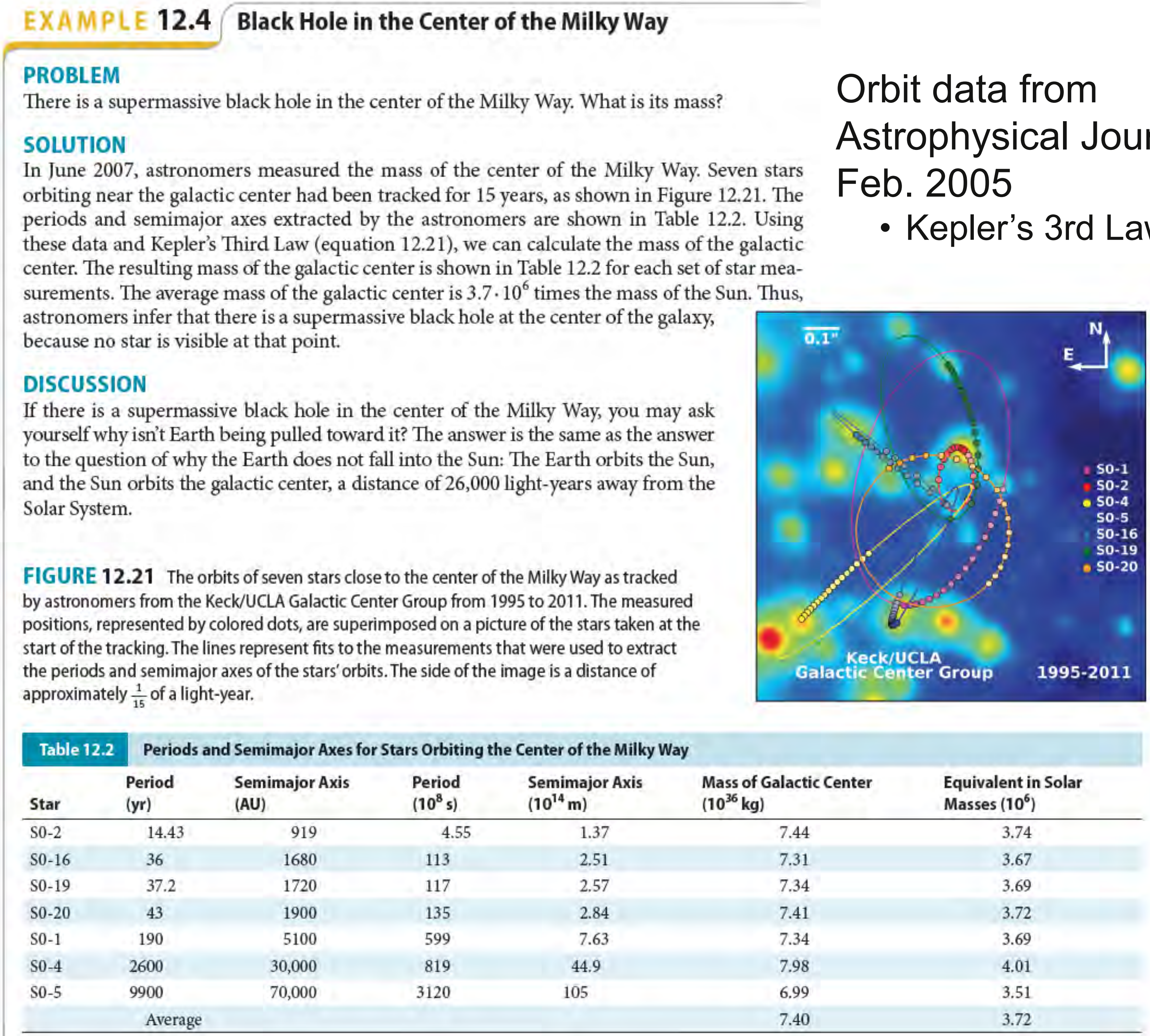


FIGURE 39.19 (a) Event display from the ATLAS collaboration at CERN, showing the decay of a Higgs boson into four muons (red tracks). (from http://www.atlas.ch/news/2012/latest-results-from-higgs-search.html) (b) Event display from the CMS collaboration at CERN, showing the decay of a Higgs boson into two photons (yellow dashed lines and green towers). (from https://cdsweb.cern.ch/record/1459463)



EXAMPLE 12.4 Black Hole in the Center of the Milky Way

PROBLEM

There is a supermassive black hole in the center of the Milky Way. What is its mass?

SOLUTION

In June 2007, astronomers measured the mass of the center of the Milky Way. Seven stars orbiting near the galactic center had been tracked for 15 years, as shown in Figure 12.21. The periods and semimajor axes extracted by the astronomers are shown in Table 12.2. Using these data and Kepler's Third Law (equation 12.21), we can calculate the mass of the galactic center. The resulting mass of the galactic center is shown in Table 12.2 for each set of star measurements. The average mass of the galactic center is $3.7 \cdot 10^6$ times the mass of the Sun. Thus, astronomers infer that there is a supermassive black hole at the center of the galaxy, because no star is visible at that point.

DISCUSSION

If there is a supermassive black hole in the center of the Milky Way, you may ask yourself why isn't Earth being pulled toward it? The answer is the same as the answer to the question of why the Earth does not fall into the Sun: The Earth orbits the Sun, and the Sun orbits the galactic center, a distance of 26,000 light-years away from the Solar System.

FIGURE 12.21 The orbits of seven stars close to the center of the Milky Way as tracked by astronomers from the Keck/UCLA Galactic Center Group from 1995 to 2011. The measured positions, represented by colored dots, are superimposed on a picture of the stars taken at the start of the tracking. The lines represent fits to the measurements that were used to extract the periods and semimajor axes of the stars' orbits. The side of the image is a distance of approximately $\frac{1}{15}$ of a light-year.

Table 12.2 Periods and Semimajor Axes for Stars Orbiting the Center of the Milky Way

Star	Period (yr)	Semimajor Axis (AU)	Period (10^8 s)	Semimajor Axis (10^{14} m)	Mass of Galactic Center (10^{36} kg)	Equivalent in Solar Masses (10^6)
S0-2	14.43	919	4.55	1.37	7.44	3.74
S0-16	36	1680	113	2.51	7.31	3.67
S0-19	37.2	1720	117	2.57	7.34	3.69
S0-20	43	1900	135	2.84	7.41	3.72
S0-1	190	5100	599	7.63	7.34	3.69
S0-4	2600	30,000	819	44.9	7.98	4.01
S0-5	9900	70,000	3120	105	6.99	3.51
	Average				7.40	3.72

Orbit data from Astrophysical Journal Feb. 2005

- Kepler's 3rd Law!

EXAMPLE 7.5 Particle Physics

The conservation laws of momentum and energy are essential for analyzing th
cle collisions at high energies, such as those produced at Fermilab's Tevatron, ne
currently the world's highest-energy proton-antiproton accelerator. (An acce
for Large Hadron Collider, began operation in 2008 at the CERN Laboratory
land, and it is more powerful than Tevatron. However, the LHC is a proton-pr

In the Tevatron accelerator, particle physicists collide protons and a
energies of 1.96 TeV (hence the name). Remember that 1 eV = $1.602 \cdot 10$
$1.96 \cdot 10^{12}$ eV = $3.1 \cdot 10^{-7}$ J. The Tevatron is set up so that the protons and a
the collider ring in opposite directions, with, for all practical purposes, ex
mentum vectors. The main particle detectors, D-Zero and CDF, are locate
regions, where protons and antiprotons collide.

Figure 7.17a shows an example of such a collision. In this computer
of one particular collision event at the D-Zero detector, the proton's initial momentum vector

Self-Test Opportunity 7.9

The length of each vector arrow in Figure 7.17b is proportional to the magnitude of the momentum vector of the particular particle. Can you determine the momentum of the nondetected particle (green arrow)?

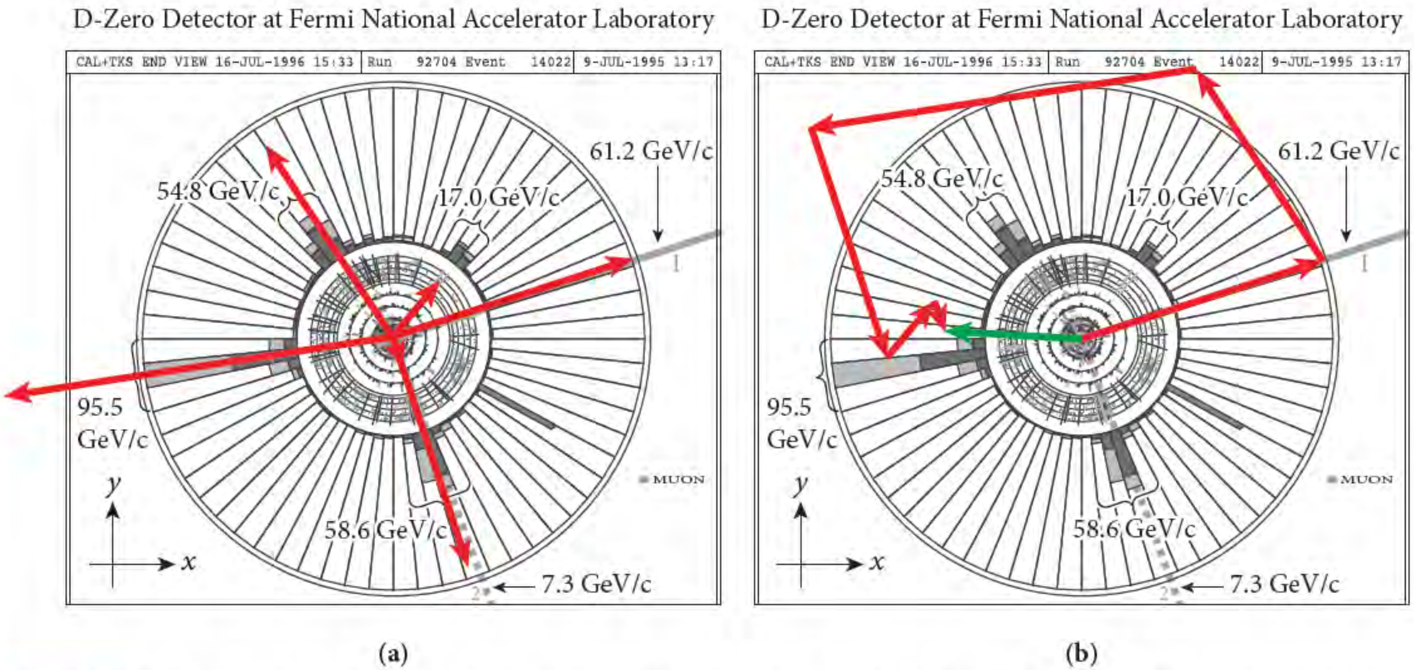
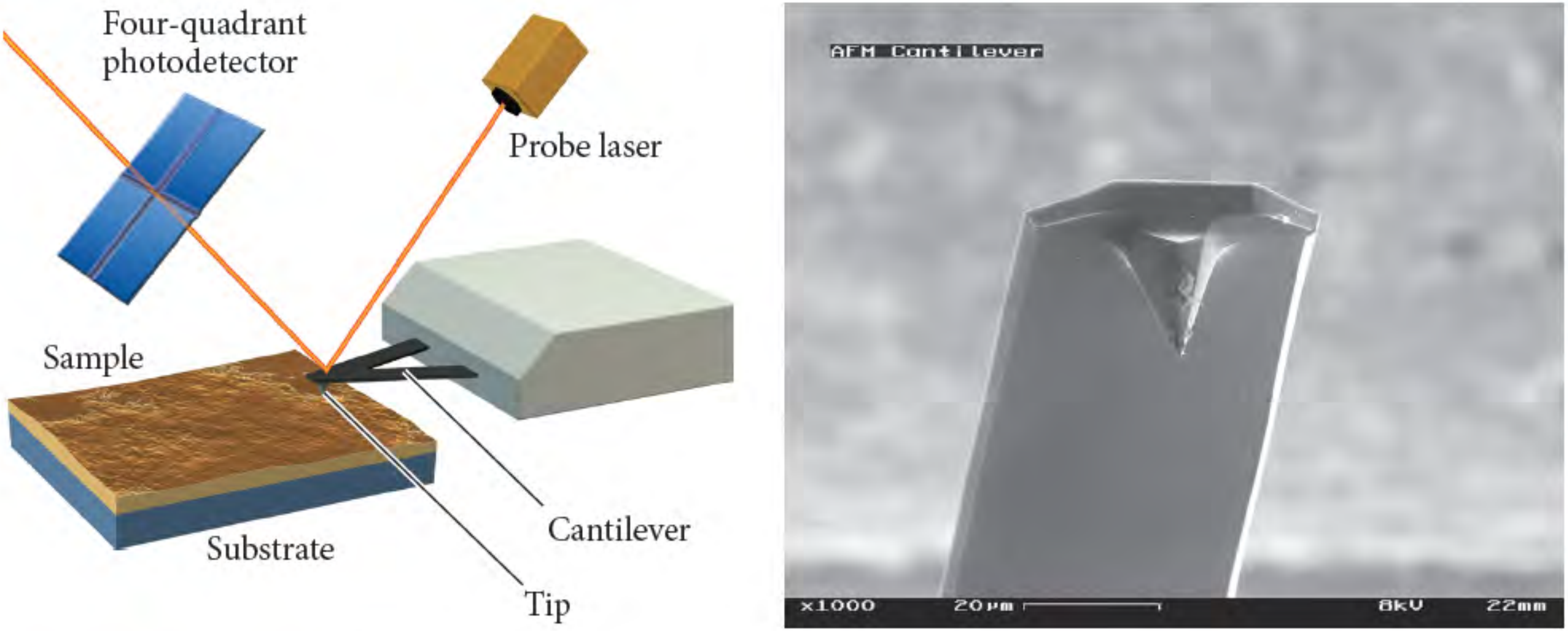


FIGURE 7.17 Event display generated by the D-Zero collaboration and education office at Fermilab, showing a top-quark event. (a) Momentum vectors of the detected particles produced by the event; (b) graphical addition of the momentum vectors, showing that they add up to a nonzero sum, indicated by the thicker green arrow.

Tribology

Atomic force microscope - AFM



(a)

(b)

FIGURE 4.22 Atomic force microscope (AFM): (a) schematic diagram of the parts of the microscope, (b) photograph (at 1000×) of the tip of the cantilever, which is dragged across the sample.

Metrology: Research on Measures and Standards

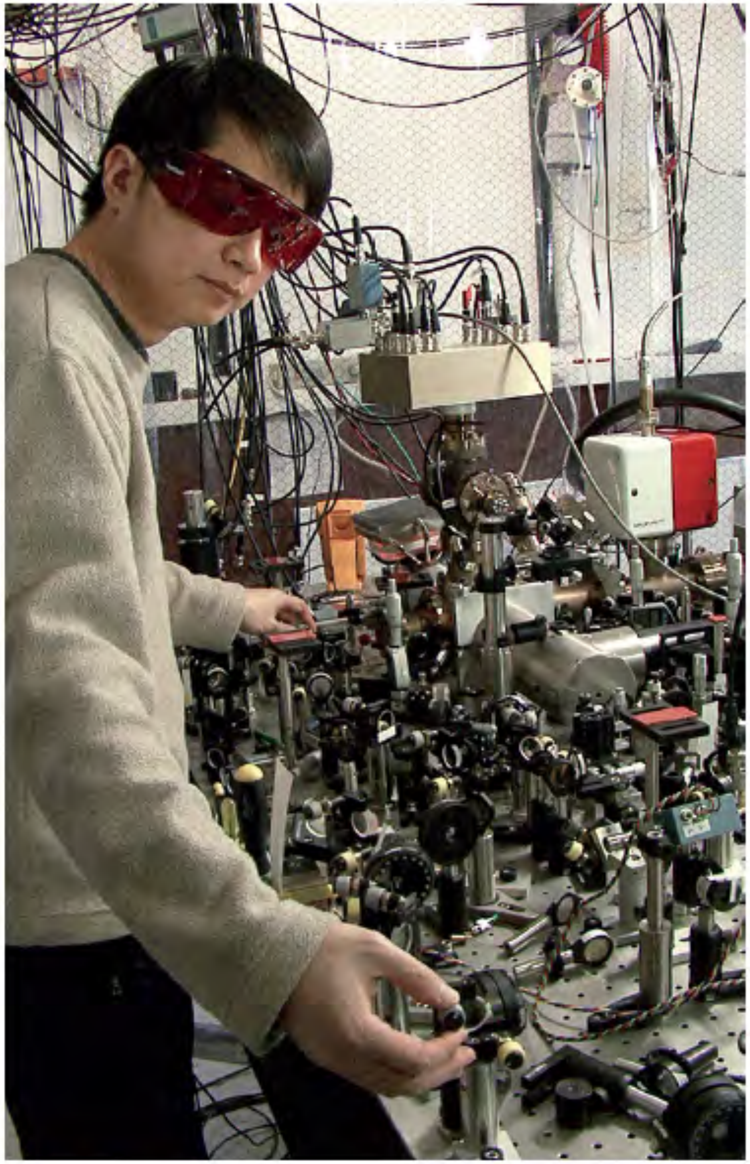


FIGURE 1.6 Setup of the world's most precise clock at NIST.

Accurate to
±1 seconds in
3.7 billion years

Energy

- No other physics topic excites students more!
- Energy examples woven throughout the text
  - **Section 5.1** *Energy in Our Daily Lives*
  - **Solved Problem 5.3** *Wind Power*
    - **Example 13.7** *Betz Limit (Wind turbines, …)*
  - **Solved Problem 6.1** *Power Produced by Niagara Falls*
  - **Example 10.8** *Flybrid*
  - **Section 17.5** *Surface Temperature of Earth* **Section 18.8** *Modes of Thermal Energy Transfer (Insulation, Gulf Stream, Global Warming, …)*
  - **Section 20.4** *Real Engines and Efficiency (Hybrid Cars, Energy Crisis, …)*

5

Kinetic Energy, Work, and Power

WHAT WE WILL LEARN 135

Tell the students first why studying this topic matters!

Application

- Real-world effects of elementary physics!
- Here: Mass, power, fuel efficiency of cars as function of time in the USA

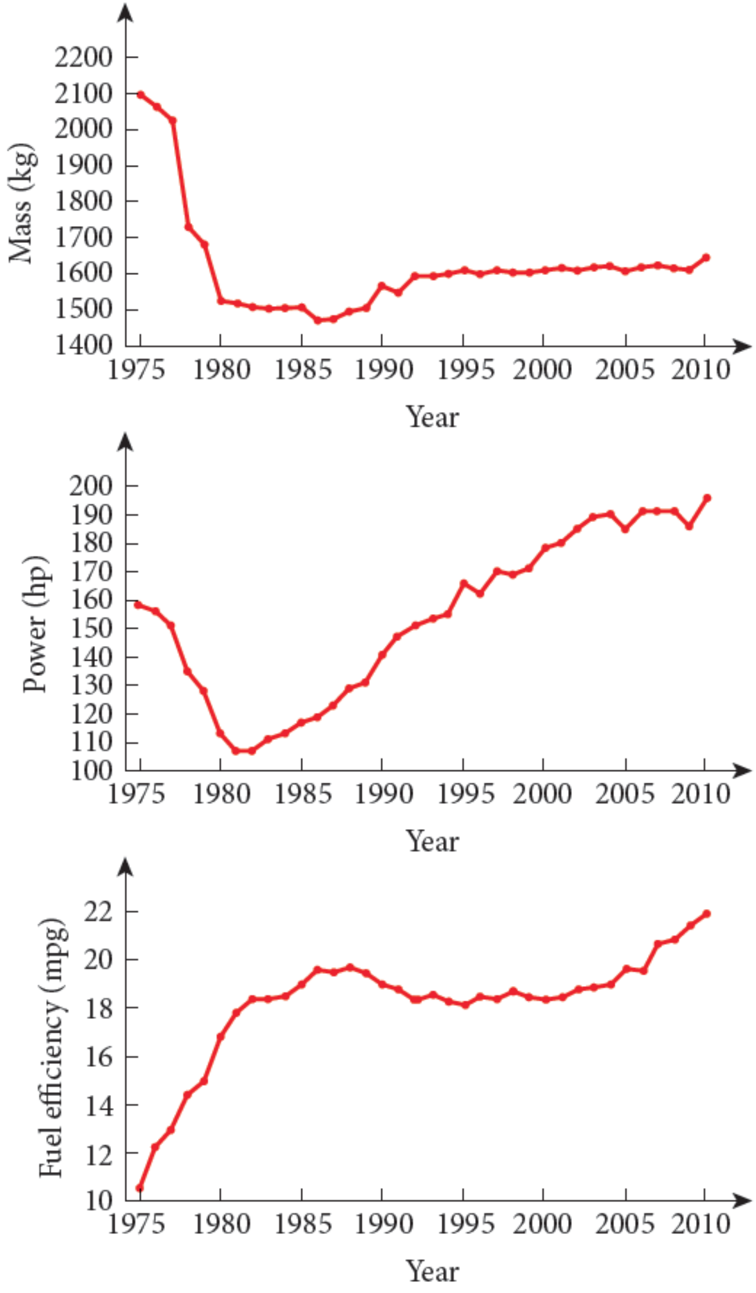


FIGURE 5.19 The mass, power, and fuel efficiency of mid-sized cars sold in the United States from 1975 to 2010. The fuel efficiency is that for typical city driving.

(originally by Steve Chu)

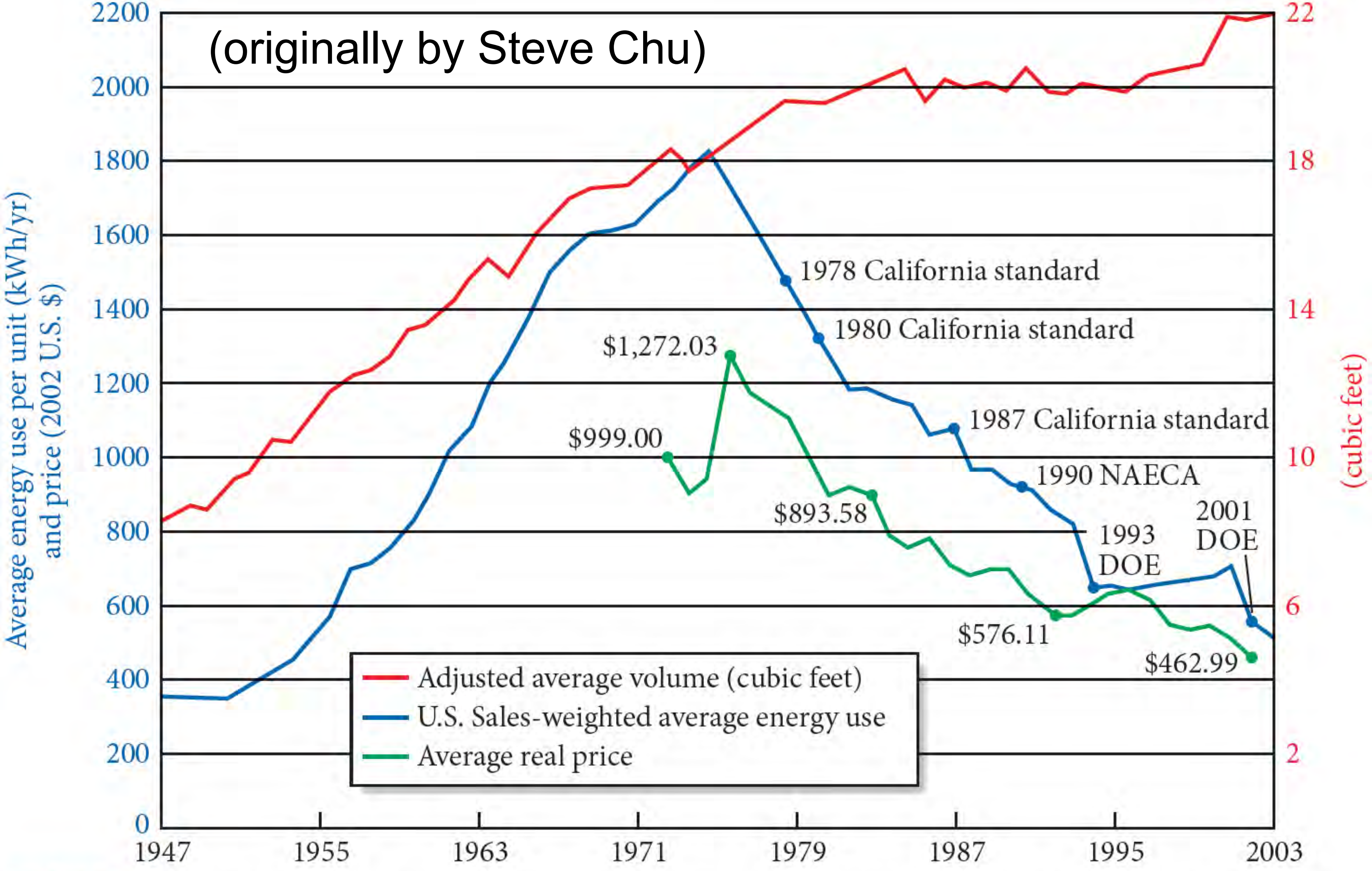
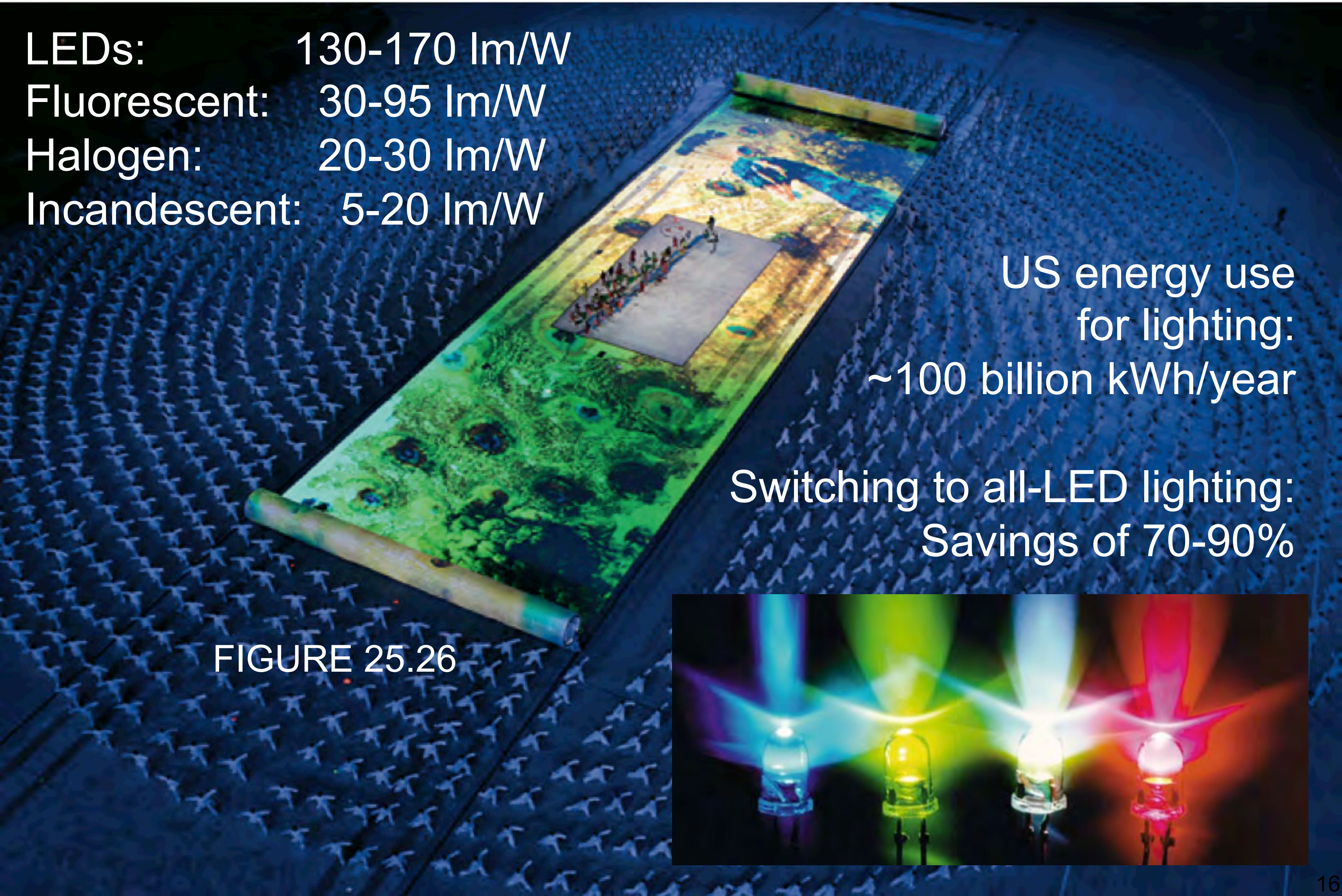


FIGURE 20.14 Average U.S. refrigerator volume (red line), price (green line), and energy use (blue line)

Efficiency Example: Lighting



LEDs: 130-170 lm/W
Fluorescent: 30-95 lm/W
Halogen: 20-30 lm/W
Incandescent: 5-20 lm/W

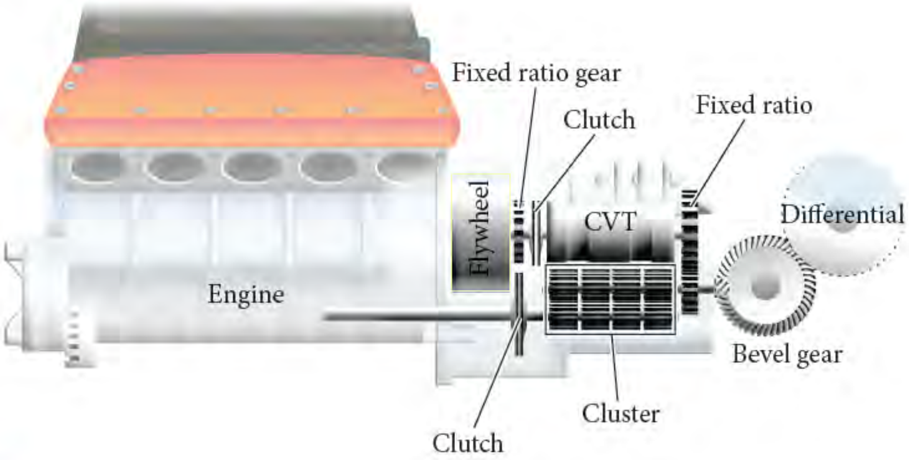
US energy use
for lighting:
~100 billion kWh/year

Switching to all-LED lighting:
Savings of 70-90%

FIGURE 25.26

EXAMPLE 10.8 Flybrid

The process of braking to slow a car down decreases the car's kinetic energy and dissipates it through the action of the friction force between the brake pads and the drums. Gas-electric hybrid vehicles convert some or most of this kinetic energy into reusable electric energy stored in a large battery. However, there is a way to accomplish this energy storage without the use of a large battery by storing the energy temporarily in a flywheel (Figure 10.33). Flywheel kinetic energy recovery systems were pioneered by Flybrid Systems and are being used in Formula 1 races and endurance races such as Le Mans.



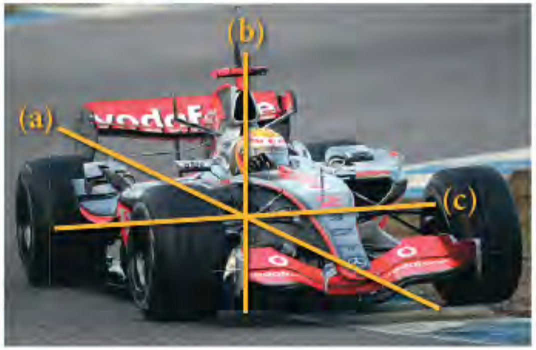
PROBLEM

A flywheel made of carbon steel has a mass of 5.00 kg, an inner radius of 8.00 cm, and an outer radius of 14.2 cm. If it is supposed to store 400.0 kJ of rotational energy, how fast (in rpm) does it have to rotate? If the rotational energy can be stored or withdrawn in 6.67 s, how much average power and torque can this flywheel deliver during that time?

Answer: *P* = 60.0 kW (80.5 hp),
***torque* = 34.6 N m**

Concept Check 10.8

The flybrid rotates fastest when the Formula 1 car is moving slowest, in the process of making a tight turn. Knowing that it takes torque to change an angular momentum vector, how would you orient the axis of rotation of the flywheel in order to have the least impact on steering the car through the curve?



a) The flywheel should be aligned with the main axis of the race car.

[✓ b) The flywheel should be vertical.]

c) The flywheel should be aligned with the wheel axles.

d) It makes no difference; all three orientations are equally problematic.

e) Orientations (a) and (c) are both equally good and better than (b).

Global Warming

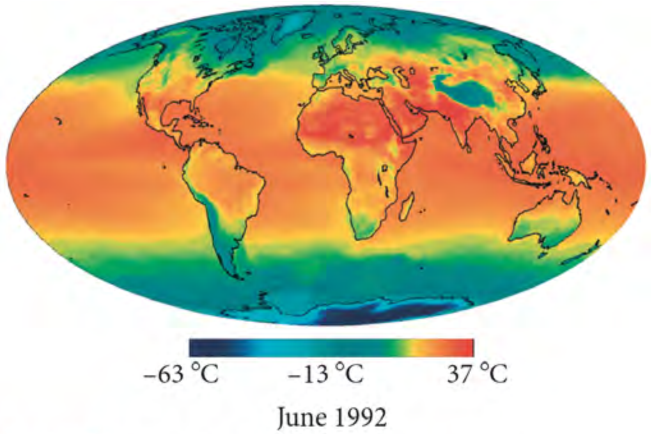


FIGURE 17.20 Time-averaged surface temperature of the Earth in June 1992. The colors represent a range of temperatures from −63 °C to +37 °C.

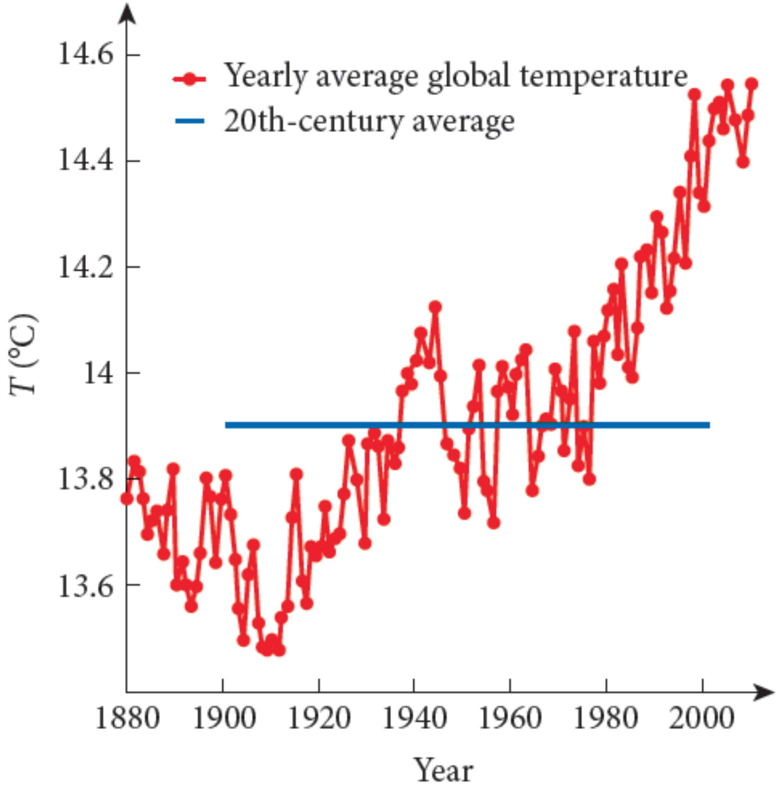


FIGURE 17.21 Annual average global surface temperature from 1880 to 2011 as measured by thermometers on land and in the ocean (red histogram). The blue horizontal line represents the average global temperature for the 20th century, 13.9 °C. (Source: Data compiled by the National Climatic Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.)

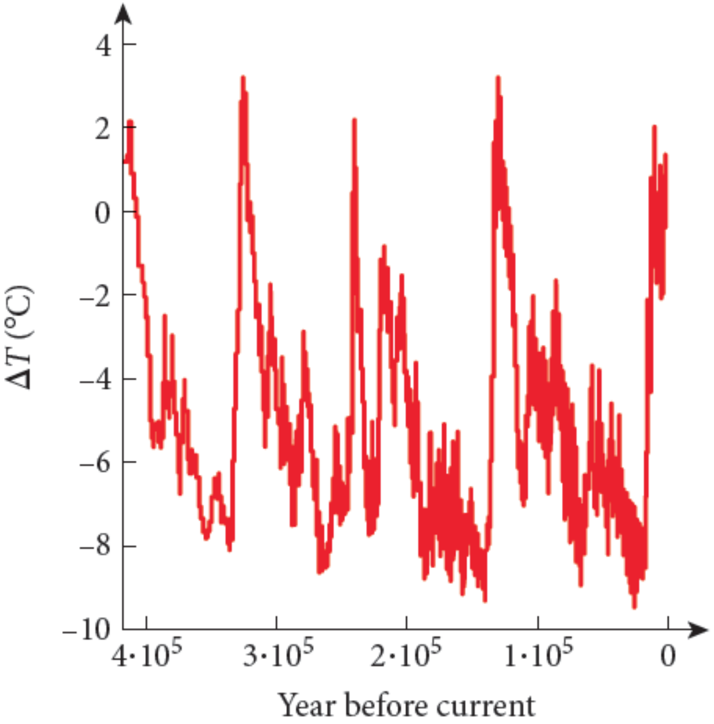


FIGURE 17.22 Average annual surface temperature of Antarctica in the past, extracted from carbon dioxide content of ice cores, relative to the present value.

Energy from the Sun

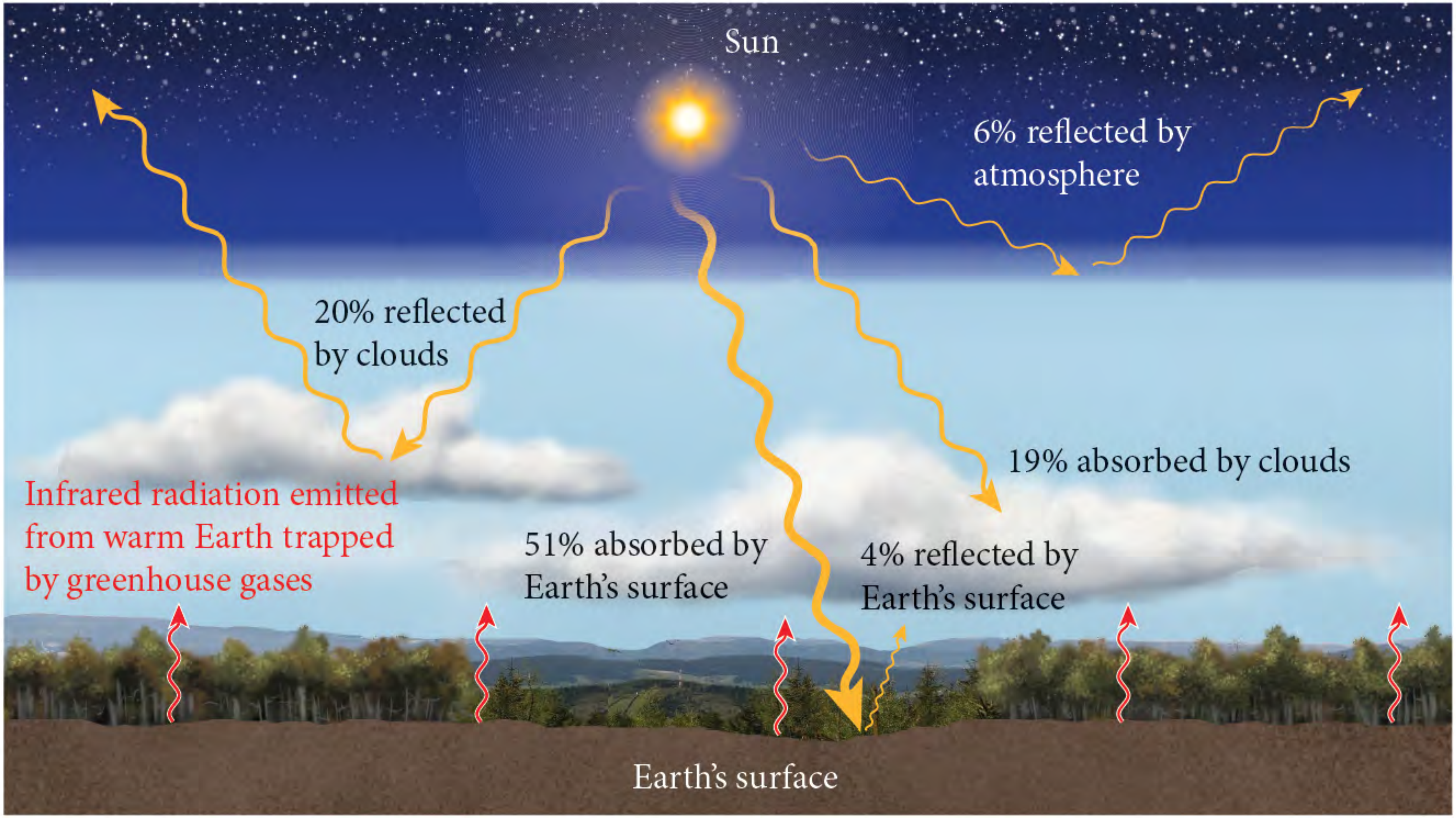


FIGURE 18.26 The Earth's atmosphere strongly affects the amount of energy absorbed by the Earth from the Sun.

CO_2 Concentration

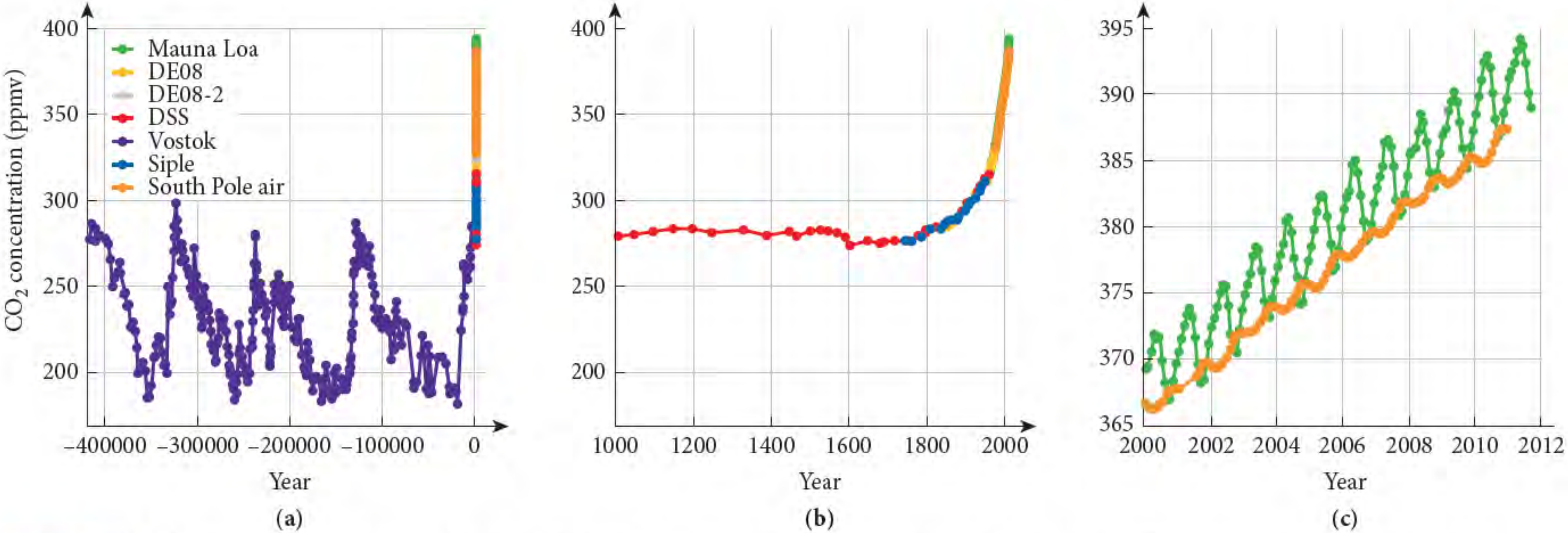


FIGURE 18.28 Concentration of carbon dioxide (CO_2) in the Earth's atmosphere in parts per million by volume (ppmv). (a) Concentration of carbon dioxide in the atmosphere during the last 420,000 years. The measurements shown are from air samples at Mauna Loa in Hawaii (green) and the South Pole (orange) and various ice core samples from Antarctica. (b) Display of the same data as in part (a), but only from 1000 AD to the present. (c) Display of the same data as in part (b), but only from 2000 to 2012.

EXAMPLE 17.4 Rise in Sea Level Due to Thermal Expansion of Water

The rise in the level of the Earth's oceans is of current concern. Oceans cover $3.6 \cdot 10^8$ km^2, slightly more than 70% of Earth's surface area. The average ocean depth is 3790 m. The surface ocean temperature varies widely, between 35 °C in the summer in the Persian Gulf and –2 °C in the Arctic and Antarctic regions. However, even if the ocean surface temperature exceeds 20 °C, the water temperature rapidly falls off as a function of depth and approaches 4 °C at a depth of 1000 m (Figure 17.23). The global average temperature of all seawater is approximately 3 °C. Table 17.3 lists a volume expansion coefficient of zero for water at a temperature of 4 °C. Thus, it is safe to assume that the volume of ocean water changes very little at a depth greater than 1000 m. For the top 1000 m of ocean water, let's assume a global average temperature of 10.0 °C and calculate the effect of thermal expansion.

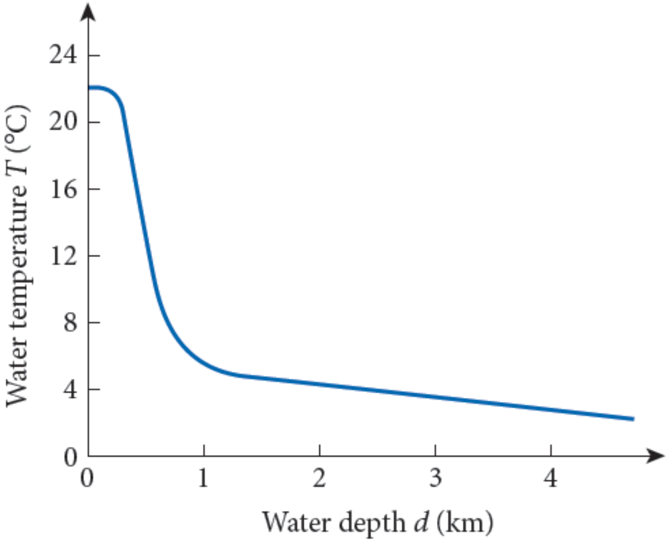


FIGURE 17.23 Average ocean water temperature as a function of depth below the surface.

PROBLEM

By how much would sea level change, solely as a result of the thermal expansion of water, if the water temperature of all the oceans increased by $\Delta T = 1.0$ °C?

SOLUTION

The volume expansion coefficient of water at 10.0 °C is $\beta = 87.5 \cdot 10^{-6}$ °C^{-1} (from Table 17.3), and the volume change of the oceans is given by equation 17.9, $\Delta V = \beta V \Delta T$, or

$$\frac{\Delta V}{V} = \beta \Delta T. \qquad \text{(i)}$$

We can express the total surface area of the oceans as $A = (0.7)4\pi R^2$, where R is the radius of Earth and the factor 0.7 reflects the fact that about 70% of the surface of the sphere is covered by water. We assume that the surface area of the oceans increases only minutely from the

Answer: 9 cm

SOLVED PROBLEM 18.4 Gulf Stream

Let's assume that a rectangular pipe of water 100 km wide and 500 m deep can approximate the Gulf Stream. The water in this pipe is moving with a speed of 2.0 m/s. The temperature of the water is 5.0 °C warmer than the surrounding water.

PROBLEM

Estimate how much power the Gulf Stream is carrying to the North Atlantic Ocean.

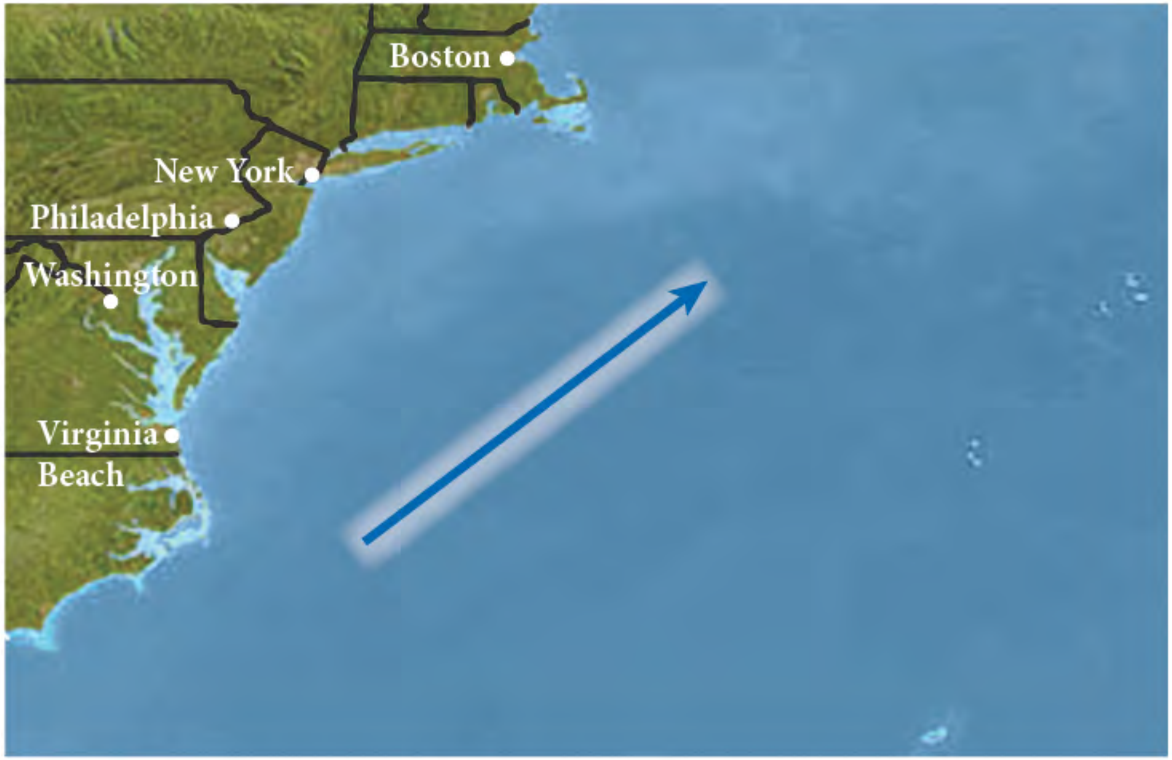


FIGURE 18.22 Idealized Gulf Stream flowing along the eastern coastline of the United States toward the North Atlantic.

Convection problem, but of global relevance

Answer: ~ 2 PW

SOLVED PROBLEM 6.1 Power Produced by Niagara Falls

PROBLEM

The Niagara River delivers an average of 5520 m^3 of water per second to the top of Niagara Falls, where it drops 49.0 m. If all the potential energy of that water could be converted to electrical energy, how much electrical power could Niagara Falls generate?

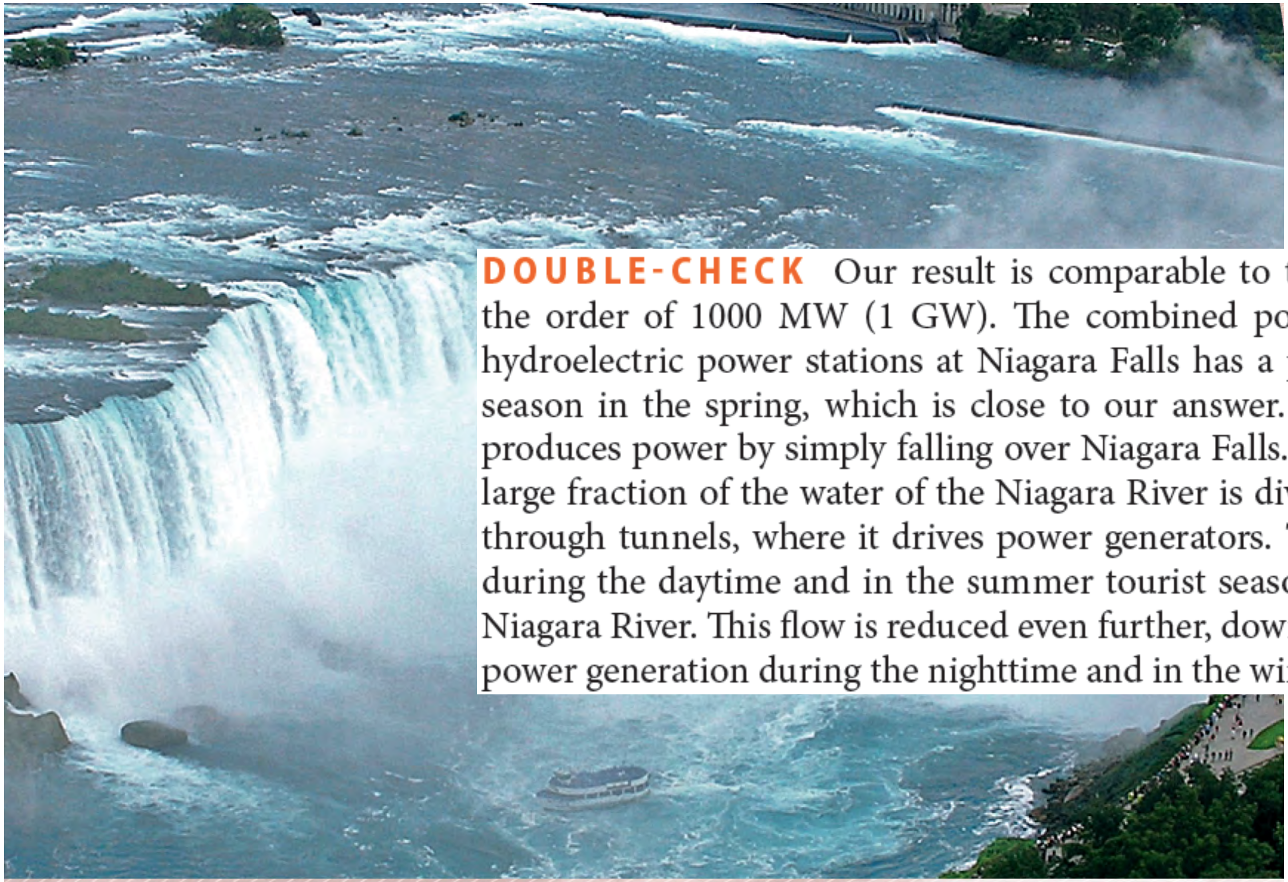


FIGURE 6.1 Niagara Falls.

Answer: 2.65 GW

DOUBLE-CHECK Our result is comparable to the output of nuclear power plants, on the order of 1000 MW (1 GW). The combined power generation capability of all of the hydroelectric power stations at Niagara Falls has a peak of 4.4 GW during the high water season in the spring, which is close to our answer. However, you may ask how the water produces power by simply falling over Niagara Falls. The answer is that it doesn't. Instead, a large fraction of the water of the Niagara River is diverted upstream from the falls and sent through tunnels, where it drives power generators. The water that makes it across the falls during the daytime and in the summer tourist season is only about 50% of the flow of the Niagara River. This flow is reduced even further, down to 10%, and more water is diverted for power generation during the nighttime and in the winter.

Supercapacitor Bus

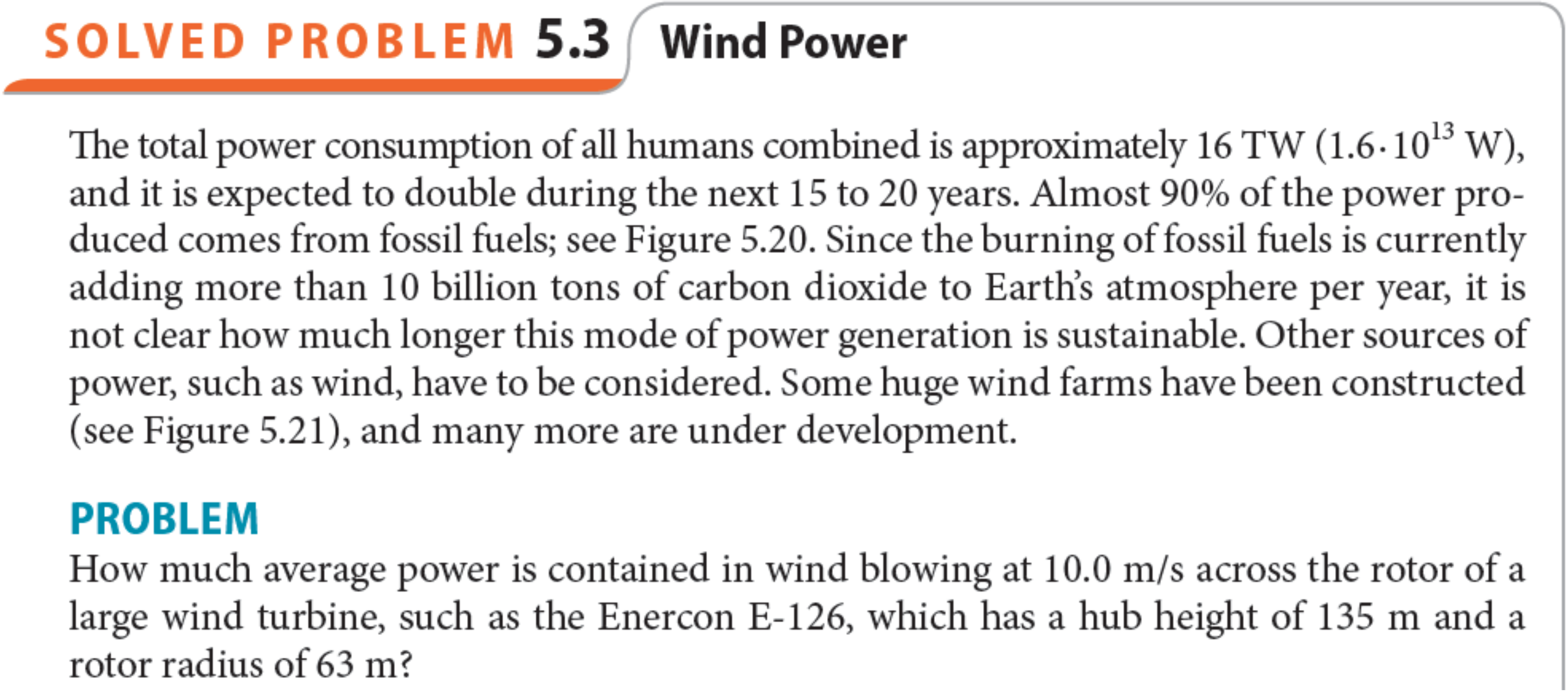
- Energy storage in capacitors for transportation - kF capacitors

FIGURE 24.33 Supercapacitor-powered bus recharging at a bus stop in Shanghai, China.

Transportation

FIGURE 27.1 The Shanghai Maglev Train in the Pudong Airport station. The inset is a display inside the train showing the maximum speed of 430 km/h (267 mph) attained during the 7-minute 20-second trip from the airport to downtown Shanghai.

Solved Problem 5.3



SOLVED PROBLEM 5.3 Wind Power

The total power consumption of all humans combined is approximately 16 TW ($1.6 \cdot 10^{13}$ W), and it is expected to double during the next 15 to 20 years. Almost 90% of the power produced comes from fossil fuels; see Figure 5.20. Since the burning of fossil fuels is currently adding more than 10 billion tons of carbon dioxide to Earth's atmosphere per year, it is not clear how much longer this mode of power generation is sustainable. Other sources of power, such as wind, have to be considered. Some huge wind farms have been constructed (see Figure 5.21), and many more are under development.

PROBLEM

How much average power is contained in wind blowing at 10.0 m/s across the rotor of a large wind turbine, such as the Enercon E-126, which has a hub height of 135 m and a rotor radius of 63 m?

Wind Power

$$P = \frac{W}{\Delta t} = \frac{\Delta K}{\Delta t} = \frac{\Delta\left(\frac{1}{2}mv^2\right)}{\Delta t} = \frac{1}{2}v^2\frac{\Delta m}{\Delta t}$$

$$P = \frac{1}{2}v^2\frac{\rho\Delta V}{\Delta t} = \frac{1}{2}v^2\frac{\rho A l}{\Delta t} = \frac{1}{2}v^2\frac{\rho\left(\pi R^2\right)\left(v\Delta t\right)}{\Delta t} = \frac{1}{2}v^3\rho\pi R^2$$

$$P = \frac{1}{2}(10.0\text{ m/s})^2\left(1.2\text{ kg/m}^3\right)\pi(63\text{ m})^2 = 7.5\text{ MW}$$

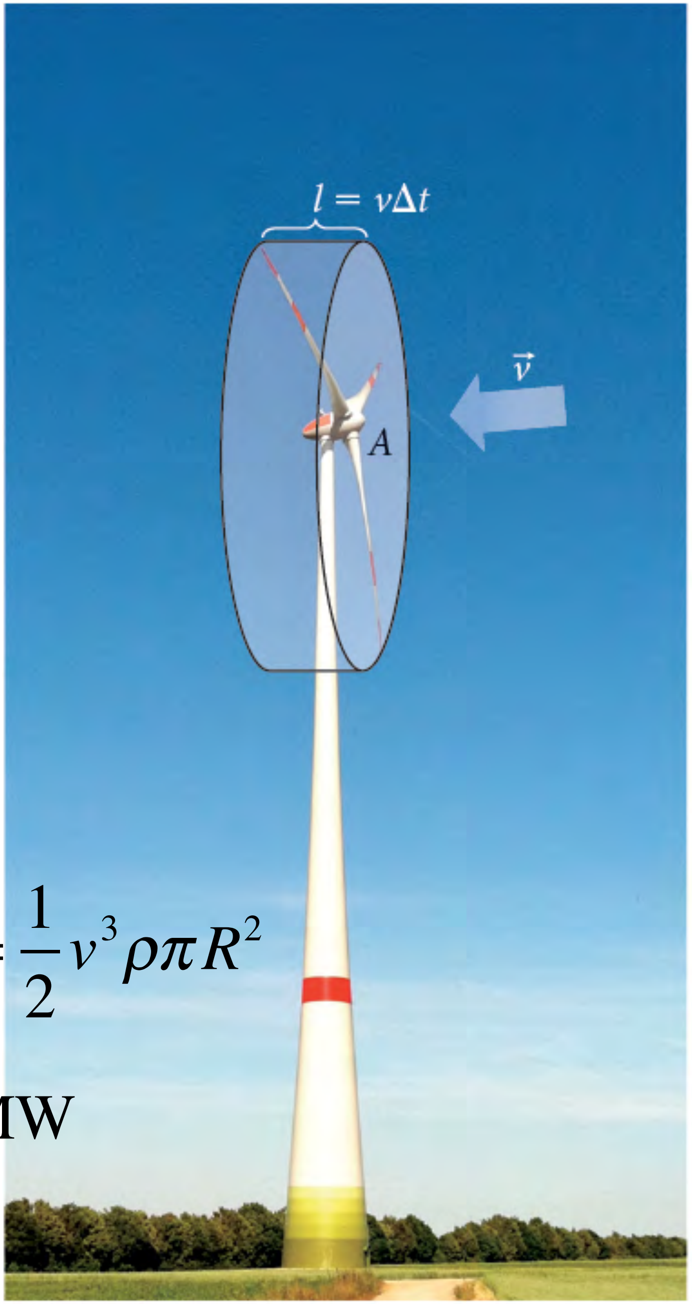


FIGURE 5.22 Sketch for finding the wind power for a large wind turbine.

EXAMPLE 13.7 Betz Limit

PROBLEM

In Chapter 5, we found that the power contained in wind moving with a speed v through an area A is $P = \frac{1}{2}Av^3\rho$, where ρ is the density of air. Now that we know about ideal fluids and energy conservation, we can derive a limit on the fraction of this power that a turbine can actually extract from the wind.

FIGURE 13.39 Wind speeds in front of, at, and behind a rotor.

Chapter 5: $P = \frac{1}{2}v^3\rho A$

Wind speed changes: $P = \frac{\Delta K}{\Delta t} = \frac{1}{2}\frac{\Delta m}{\Delta t}\left(v_1^2 - v_2^2\right)$

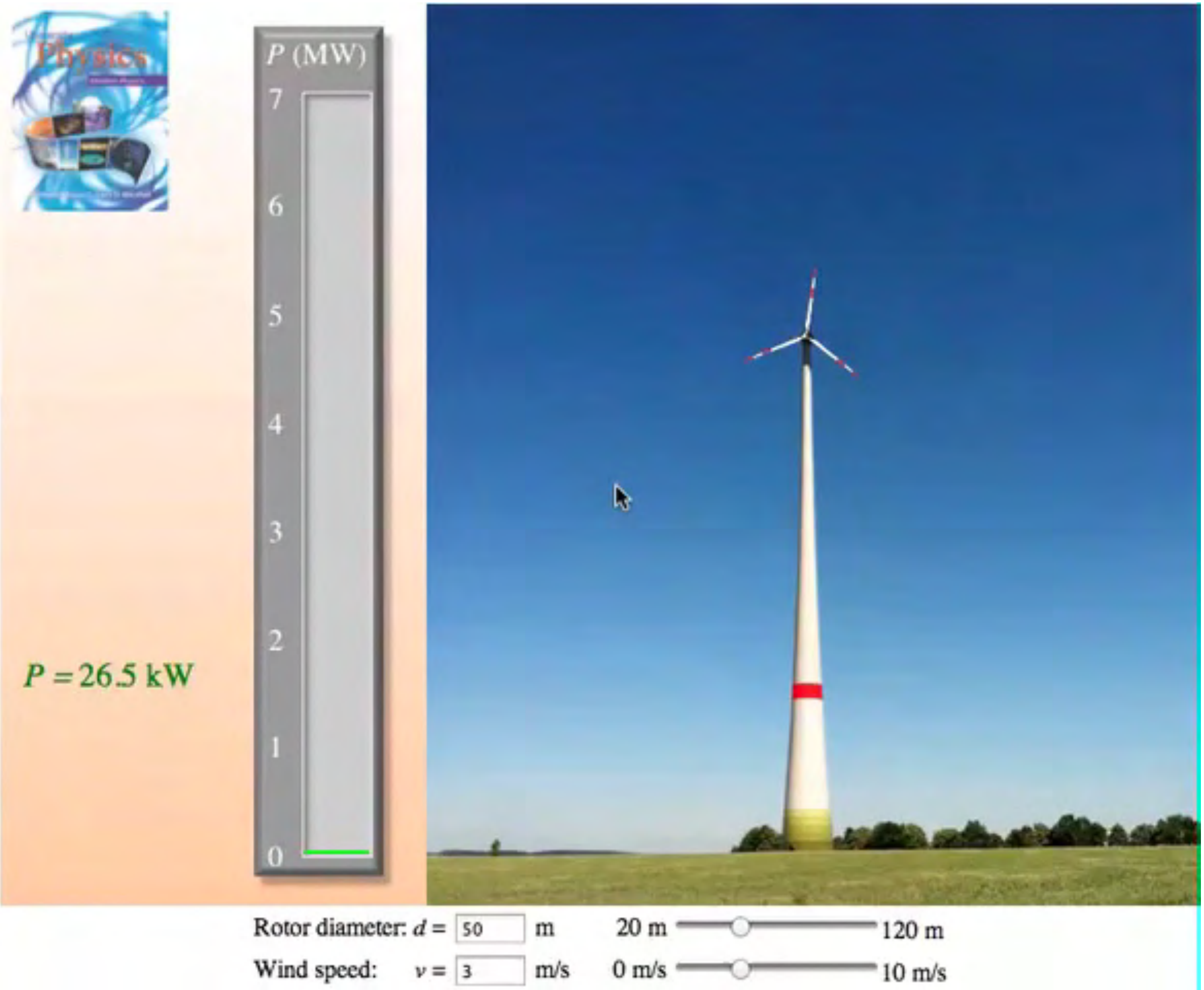
$$P = \frac{1}{2}v_1^3\rho A f\left(\chi\right),\ \chi \equiv v_2 / v_1$$

$$f\left(\chi\right) = 1 + \chi - \chi^2 - \chi^3$$

$$\chi_{\mathrm{m}} = \frac{1}{3}, f\left(\chi_{\mathrm{m}}\right) = 0.593$$

59.3% of wind power can be extracted

Interactive Exercise



$P = 26.5$ kW

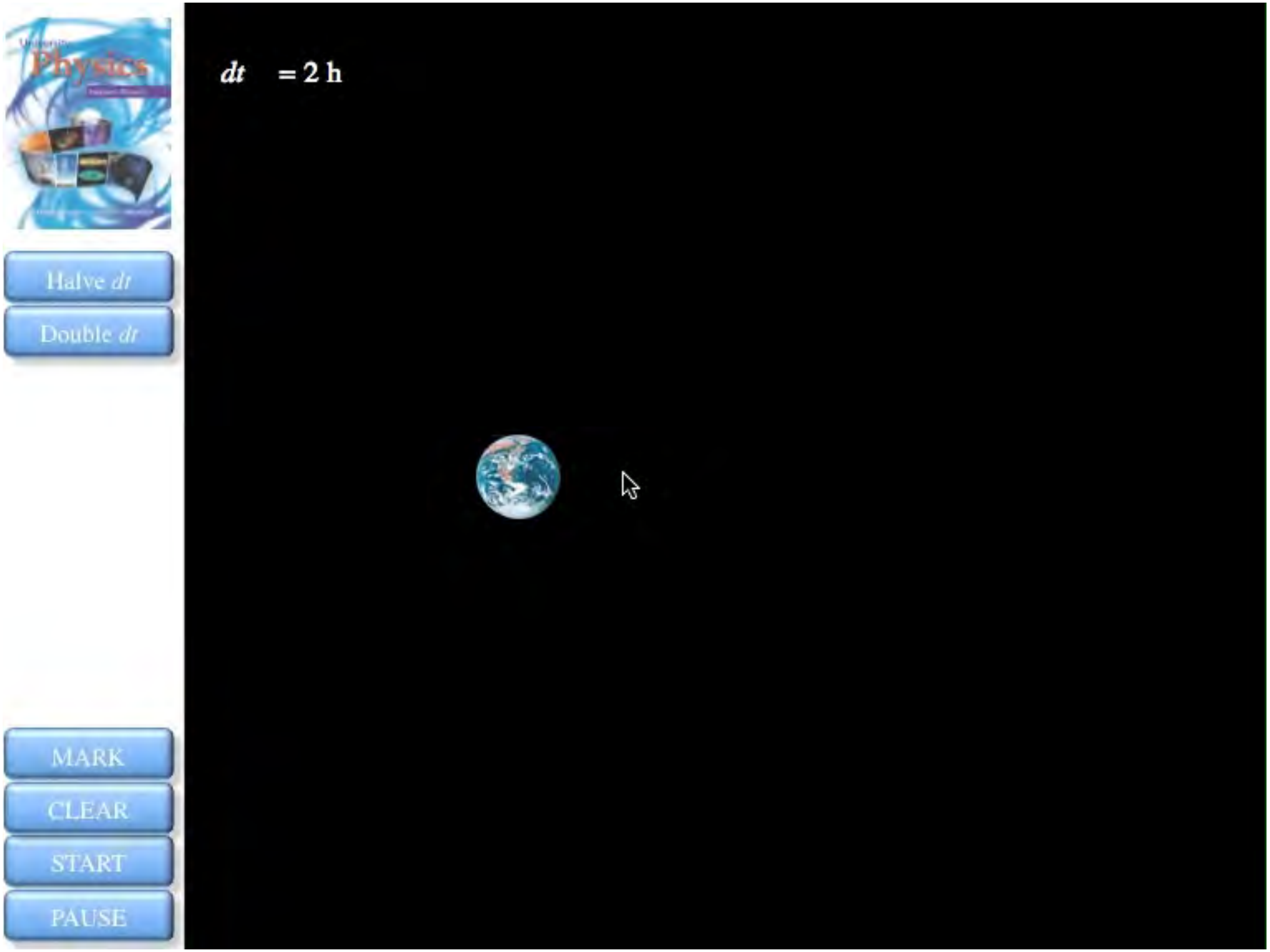
Rotor diameter: d = 50 m

Wind speed: v = 3 m/s

Interactive Apps

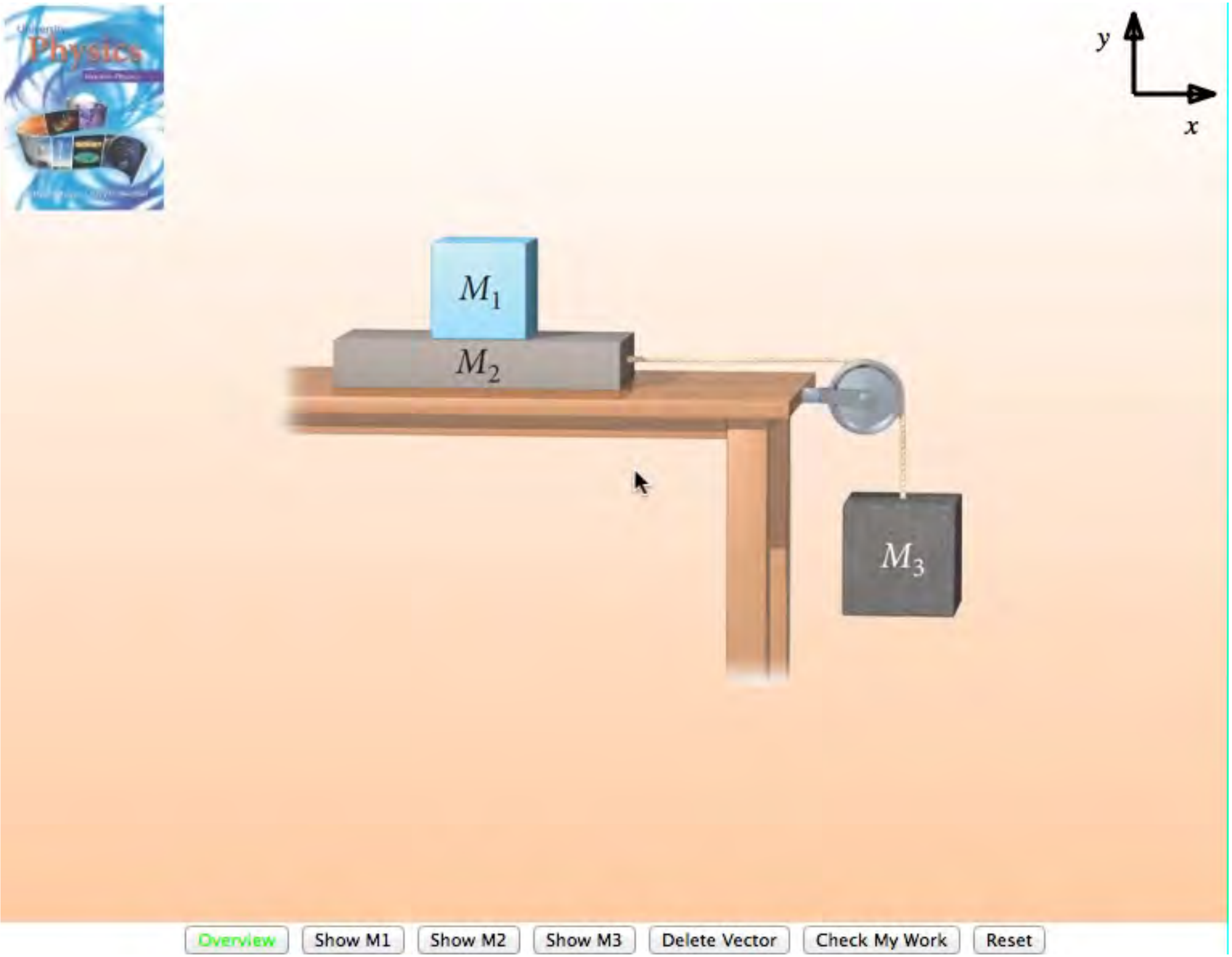
- More than **500** included in e-book (published 2014)
  - Concept checks
  - Self-test opportunities
  - Videos
  - Apps that allow study of physics systems an their parameters
- Run on all computer platforms (Windows, Mac, Linux) and all browsers
- Run also on iPhone, iPad, Android, and other mobile devices

Kepler App

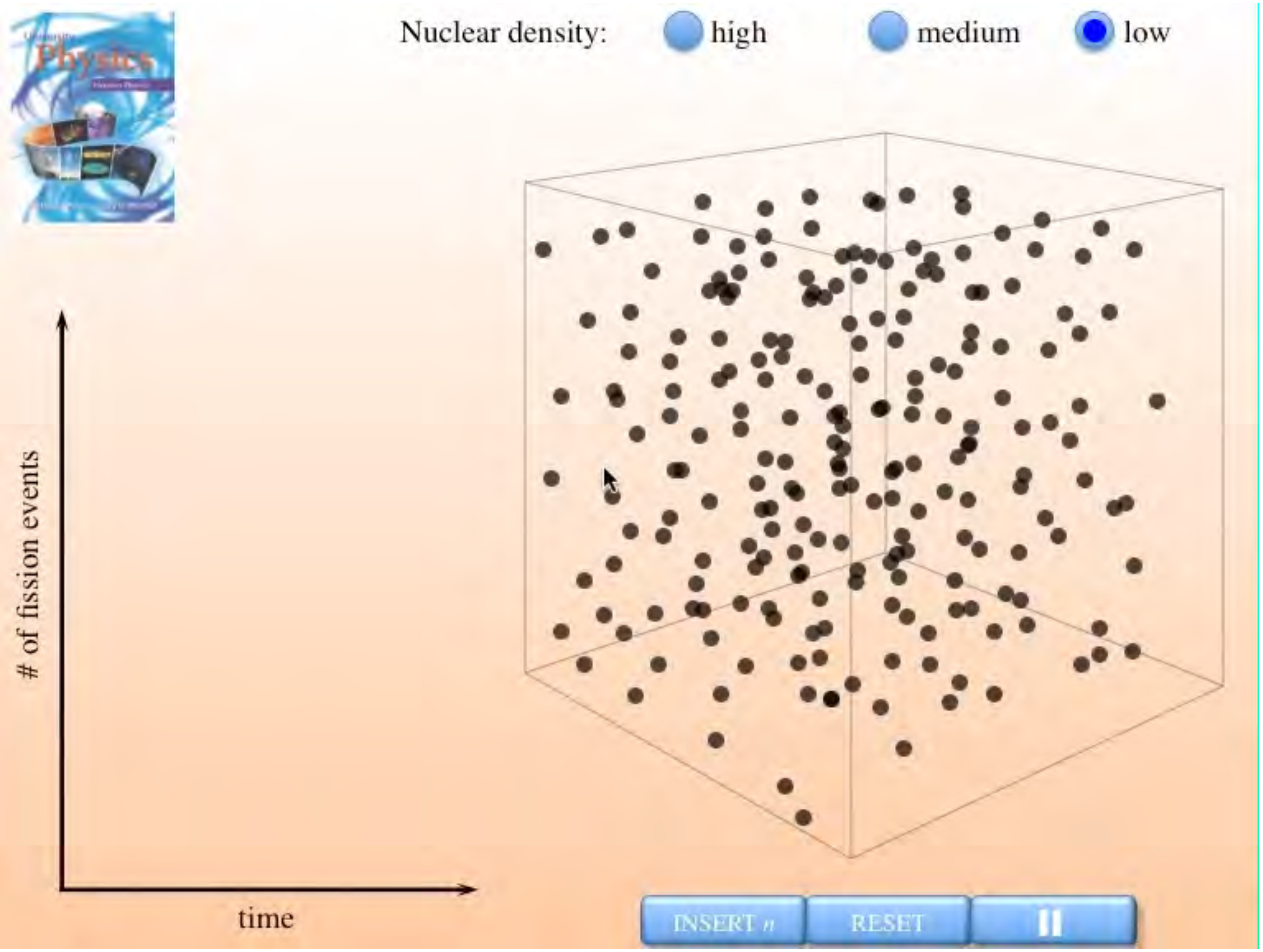


dt = 2 h

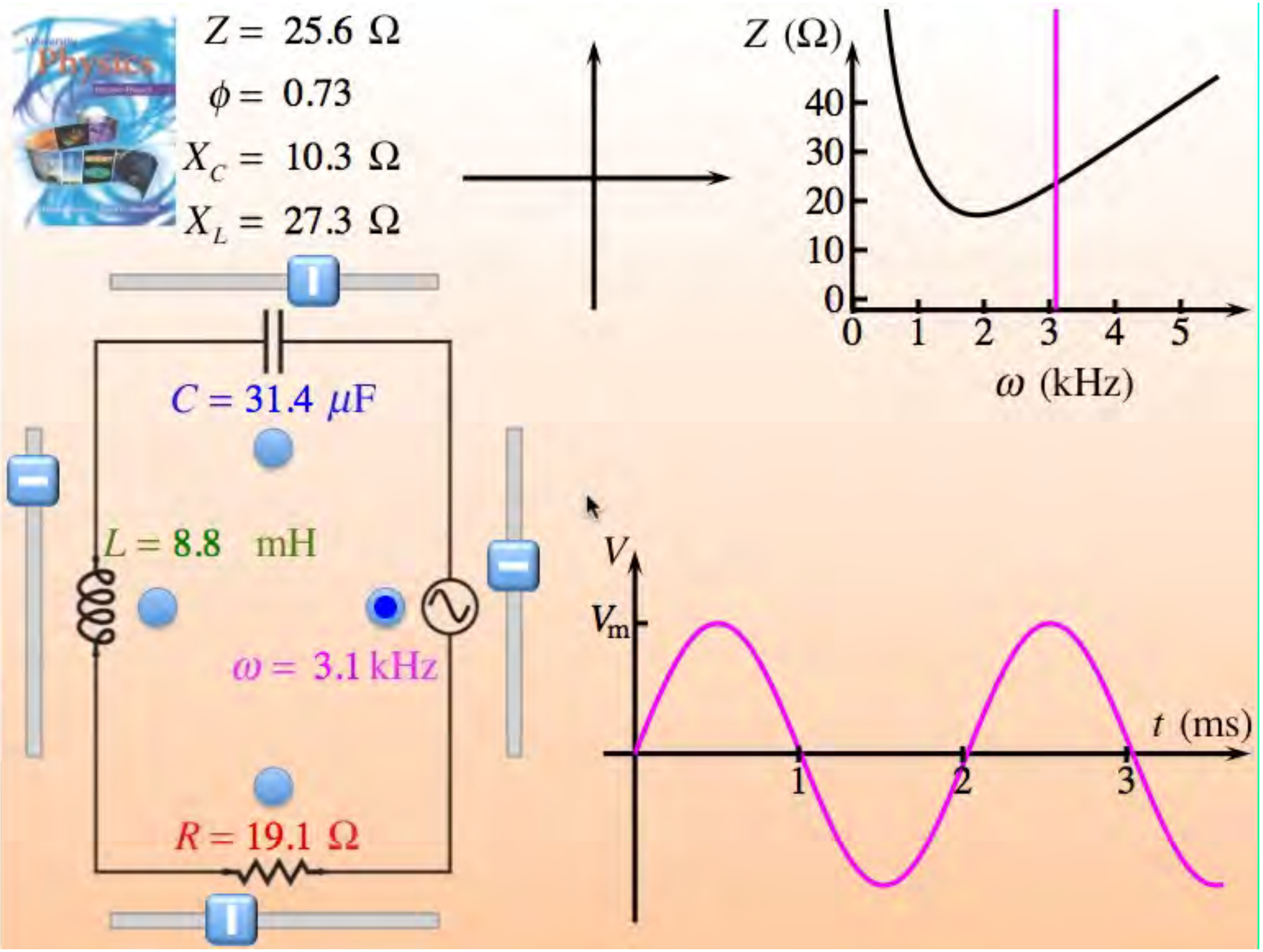
Free-Body App



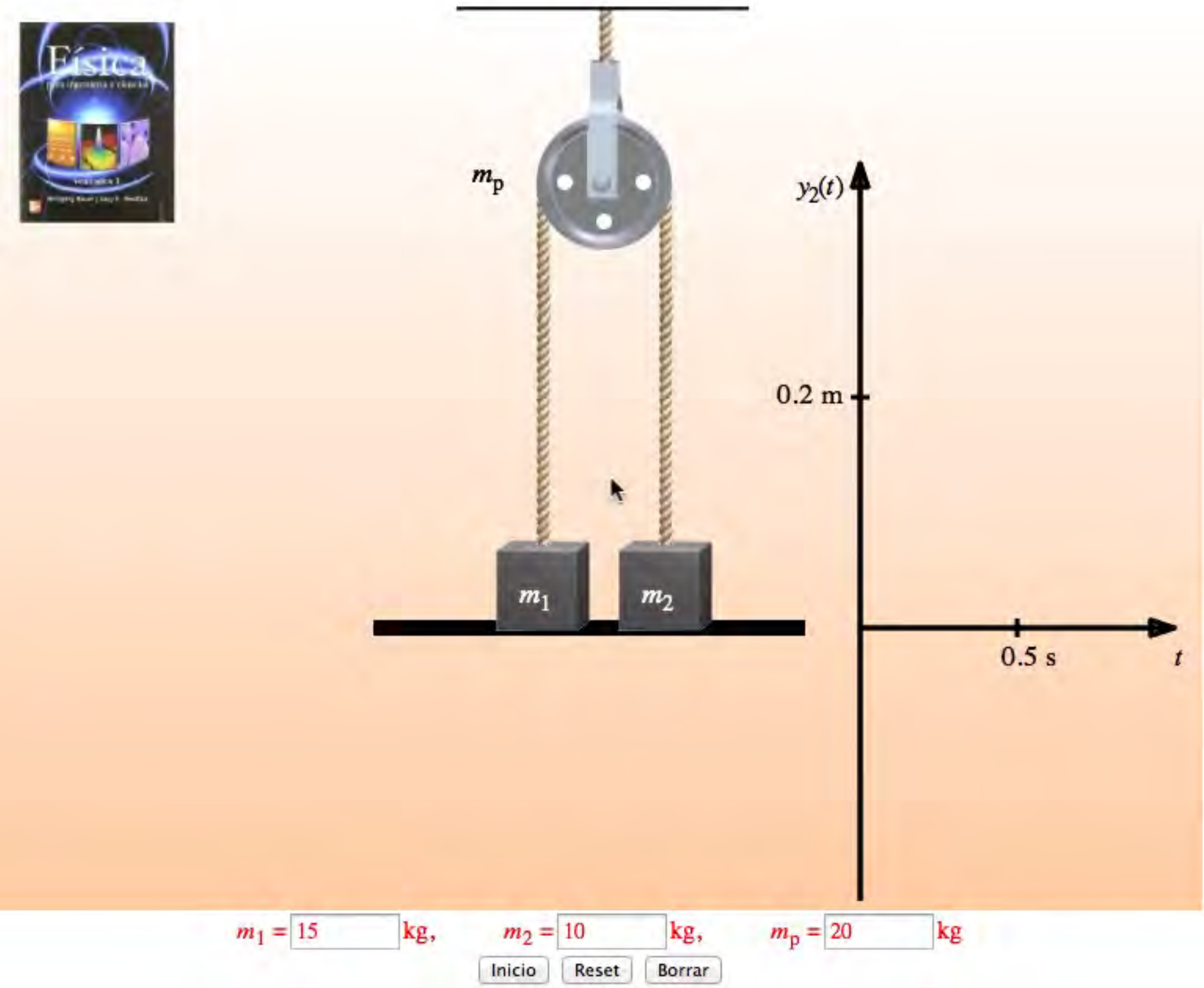
Chain Reaction App



RLC Circuit App

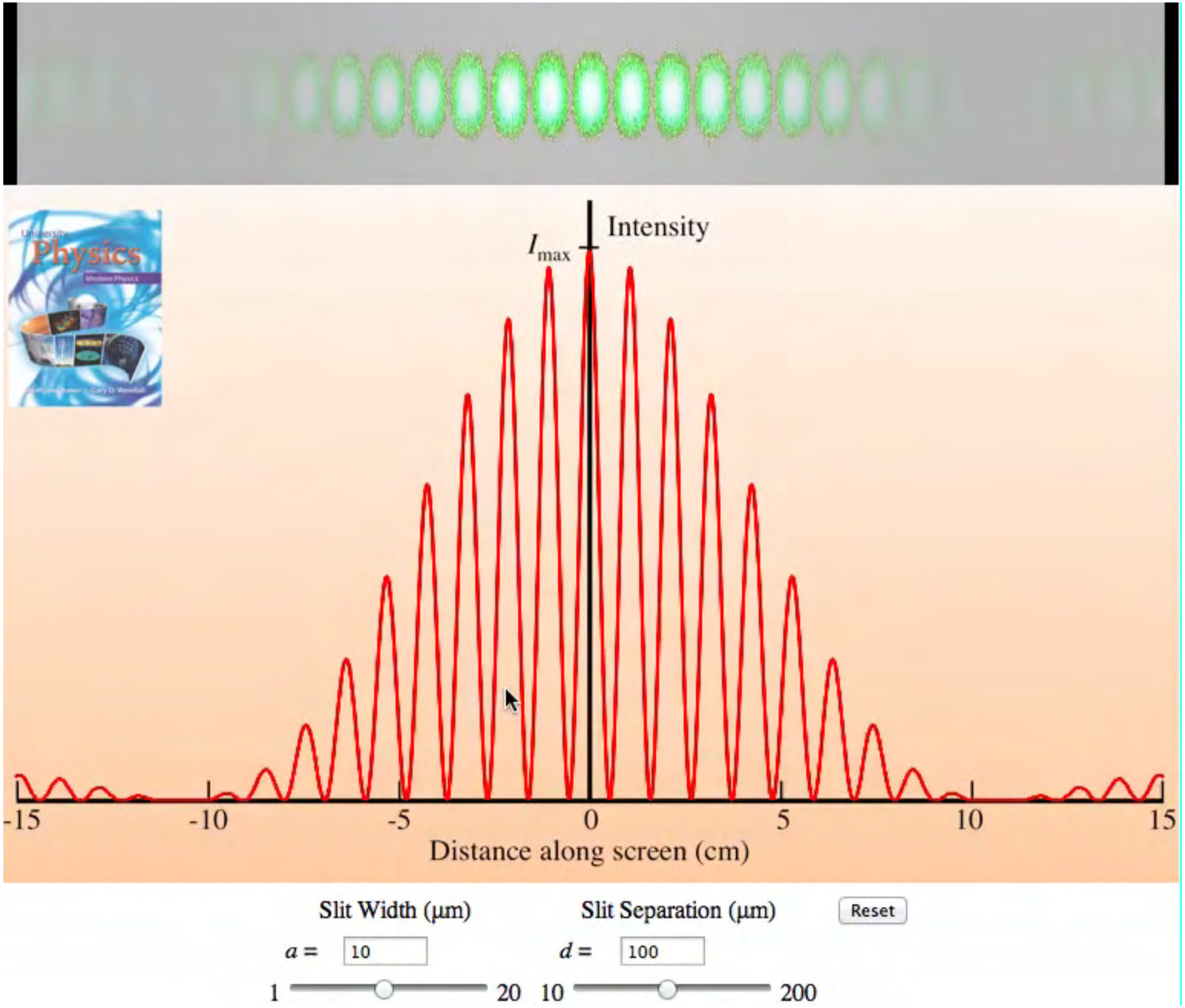


Máquina Atwood



$m_1 =$ 15 kg, $m_2 =$ 10 kg, $m_p =$ 20 kg

Interactive Exercises



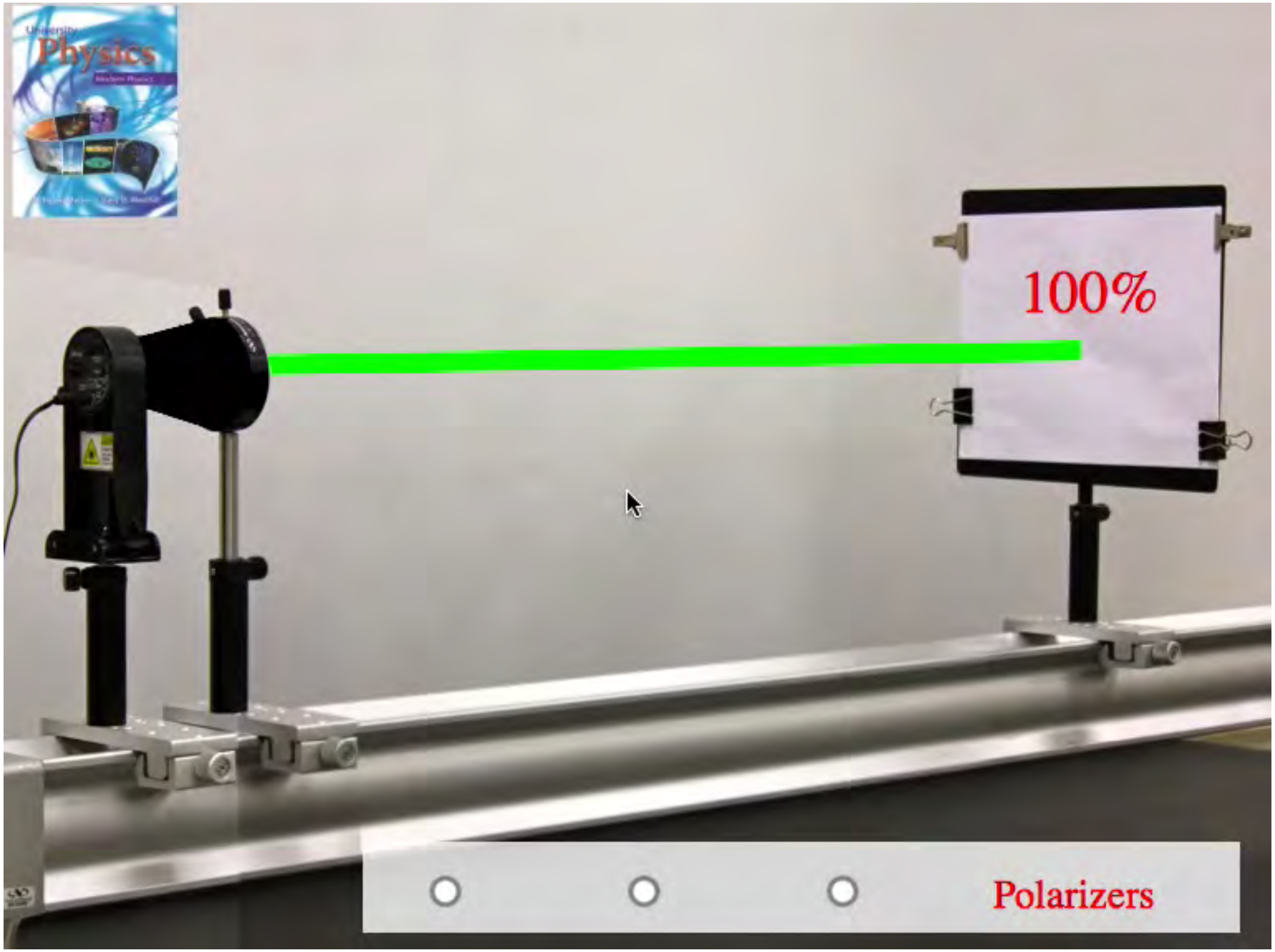
Slit Width (μm)

a = 10

Slit Separation (μm)

d = 100

Interactive Exercises



Lecture Demonstration Videos

- Recorded all intro lecture demonstrations
- Instructor can include each into VU lectures

Lecture Demonstrations Videos

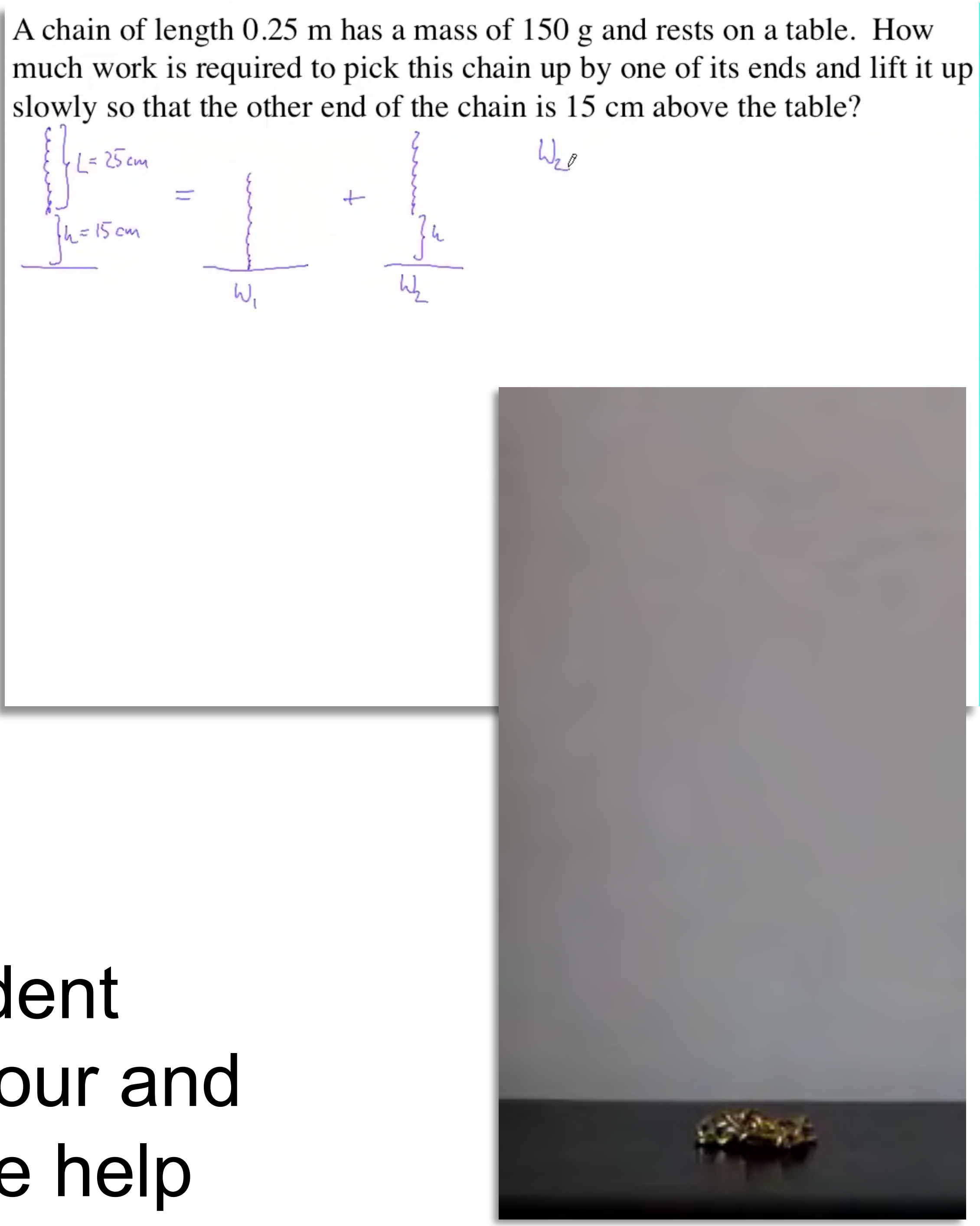
Time-lapse

Real-time

Slow-motion

Lectures

- 5-7 minute segments
- Camtasia or Tegrity screen captures with voice-over
- No talking head
- Try to capture experience of student coming to office hour and getting one-on-one help



A chain of length 0.25 m has a mass of 150 g and rests on a table. How much work is required to pick this chain up by one of its ends and lift it up slowly so that the other end of the chain is 15 cm above the table?

MULTI-VERSION EXERCISES

13.90 One can use turbines to exploit the energy contained in ocean currents, just like one can do it for wind. What is the maximum amount of power that can be extracted from a current flowing with a speed of 1.35 m/s, if one uses a turbine with rotor diameter of 24.5 m? (*Hint 1:* The density of seawater is 1024 kg/m^3. *Hint 2:* The Betz limit applies to any fluid, including seawater.)

13.91 One can use turbines to exploit the energy contained in ocean currents, just like one can do it for wind. If the maximum amount of power is 571.8 kW, which can be extracted from a current flowing with a speed of 1.57 m/s, what is the rotor diameter of the turbine? (*Hint 1:* The density of seawater is 1024 kg/m^3. *Hint 2:* The Betz limit applies to any fluid, including seawater.)

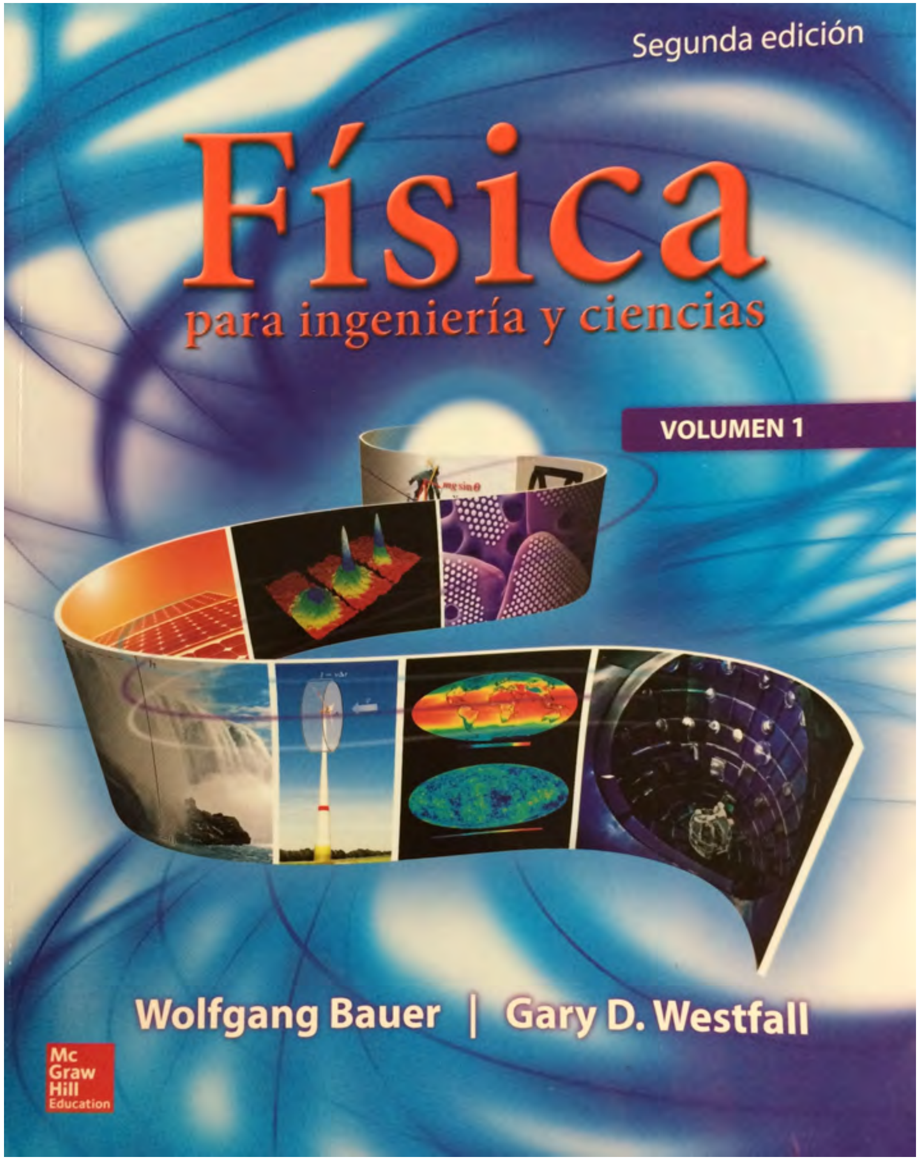
13.92 One can use turbines to exploit the energy contained in ocean currents, just like one can do it for wind. If the maximum amount of power is 918.8 kW, which can be extracted from an ocean current with a turbine of rotor diameter 25.5 m, what is the speed of the ocean current? (*Hint 1:* The density of seawater is 1024 kg/m^3. *Hint 2:* The Betz limit applies to any fluid, including seawater.)

Multi-Version Exercises

- Teach concept in class, perhaps solve a problem
- Assign another version of this problem for homework
- Test yet another version of the same problem in exam
- Student see strong connections between lectures & homework & exams
- Approximately 400 Multi-Version Exercises included in book and homework systems

Computer-Assisted Homework

- McGraw-Hill Connect+
  - With Maple integration
- Web-Assign
- LON-CAPA / CourseWeaver
  - Open source



Segunda edición

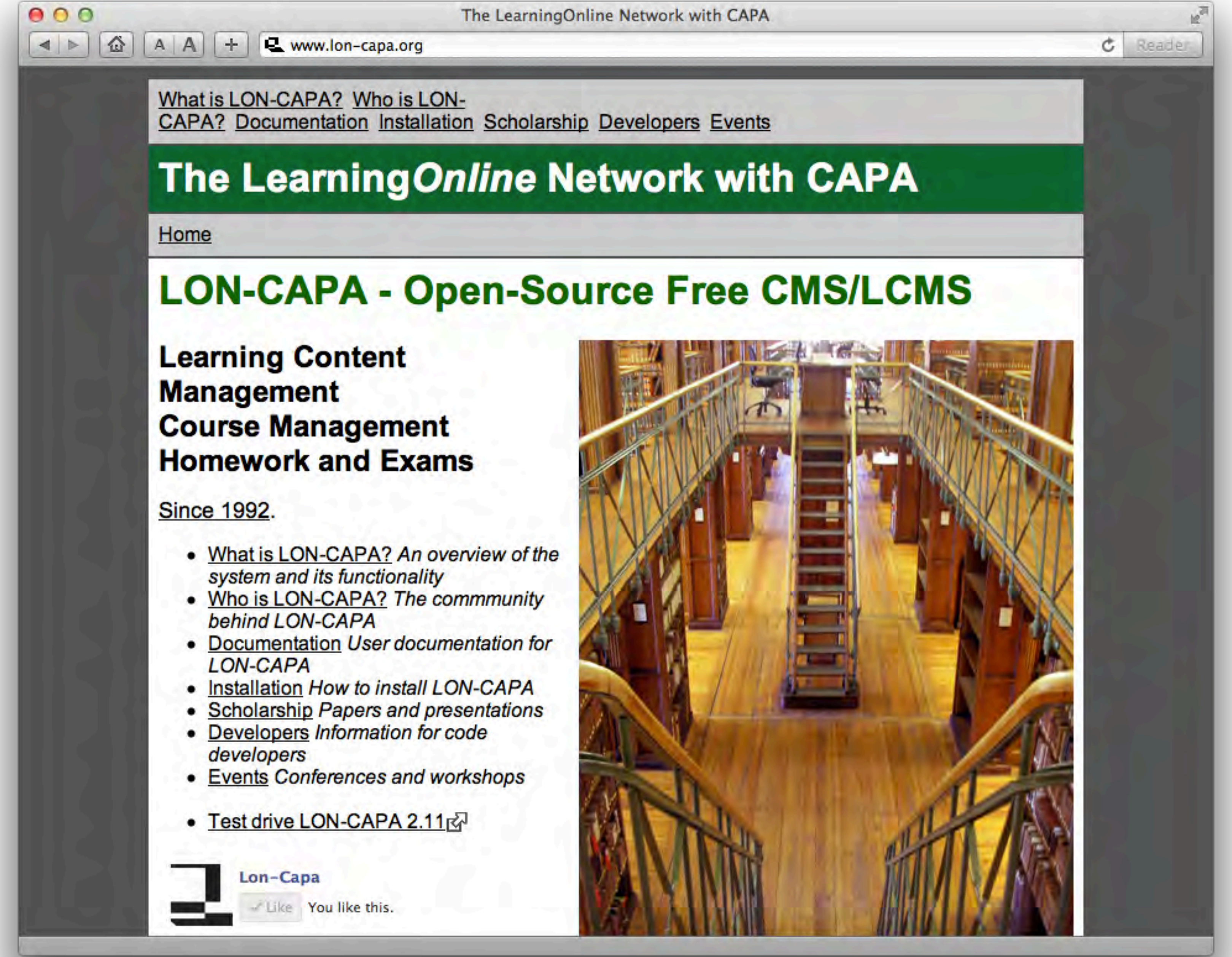
Física

para ingeniería y ciencias

VOLUMEN 1

Wolfgang Bauer | Gary D. Westfall

Mc Graw Hill Education



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The Learning*Online* Network with CAPA

Home

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Course Management
Homework and Exams

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- Who is LON-CAPA? *The commmunity behind LON-CAPA*
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- Scholarship *Papers and presentations*
- Developers *Information for code developers*
- Events *Conferences and workshops*

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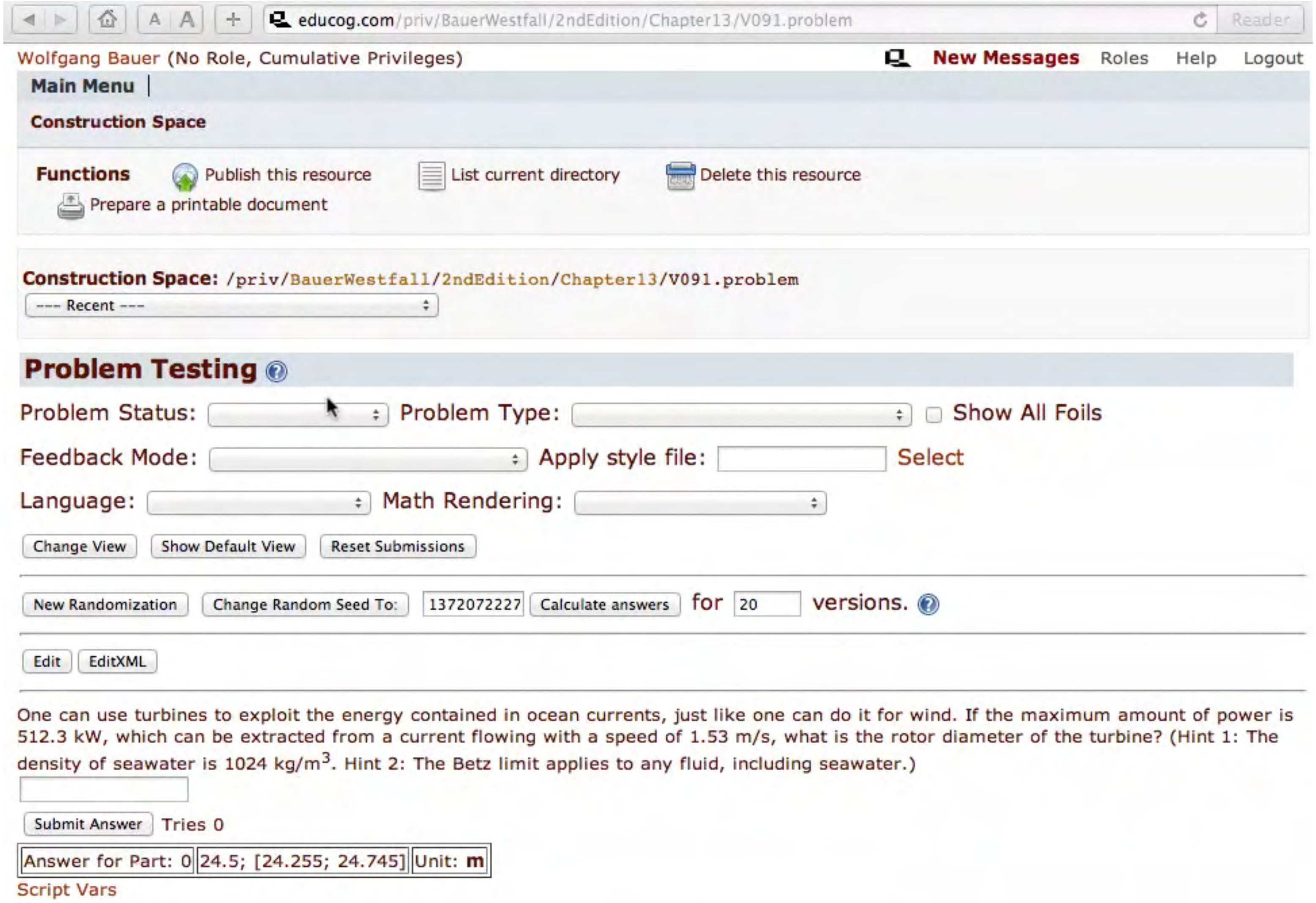
Computer-Assisted Homework



Construction Space: /priv/BauerWestfall/2ndEdition/Chapter13/V091.problem

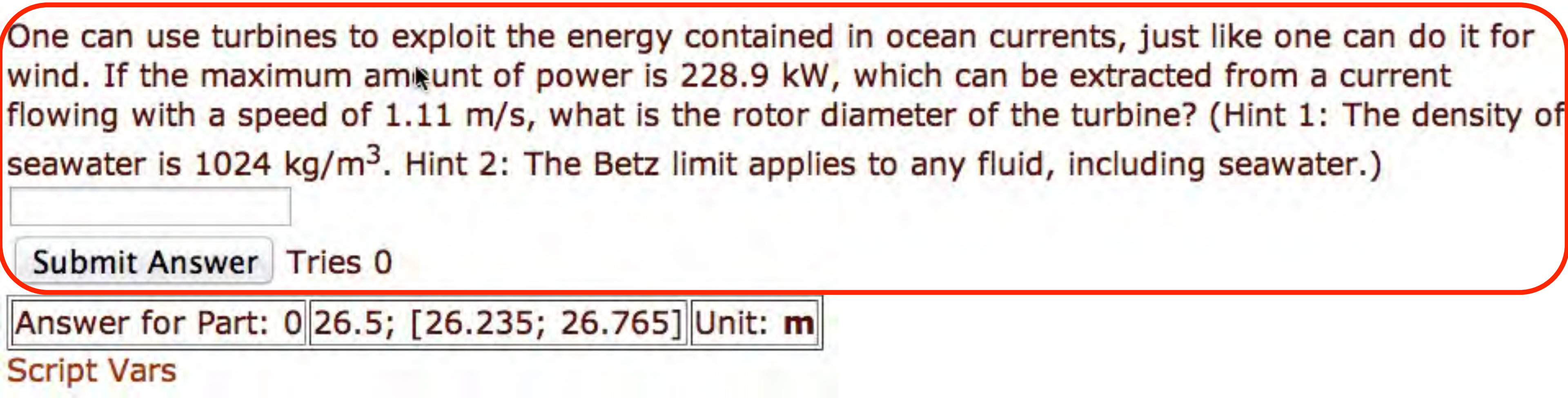
One can use turbines to exploit the energy contained in ocean currents, just like one can do it for wind. If the maximum amount of power is 512.3 kW, which can be extracted from a current flowing with a speed of 1.53 m/s, what is the rotor diameter of the turbine? (Hint 1: The density of seawater is 1024 kg/m^3. Hint 2: The Betz limit applies to any fluid, including seawater.)

Tries 0

Answer for Part: 0	24.5; [24.255; 24.745]	Unit: **m**

Computer-Assisted Homework

Student view



One can use turbines to exploit the energy contained in ocean currents, just like one can do it for wind. If the maximum amount of power is 228.9 kW, which can be extracted from a current flowing with a speed of 1.11 m/s, what is the rotor diameter of the turbine? (Hint 1: The density of seawater is 1024 kg/m^3. Hint 2: The Betz limit applies to any fluid, including seawater.)

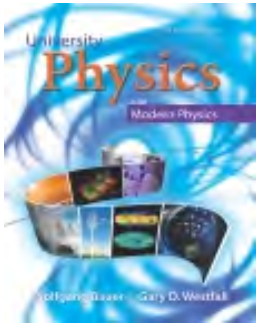
Answer for Part: 0	26.5; [26.235; 26.765]	Unit: **m**

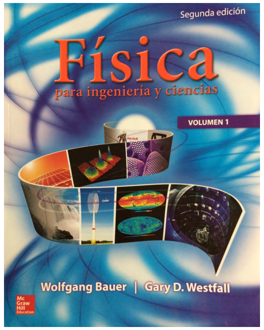
Computer-Assisted Homework

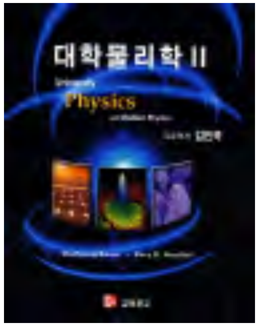
- All homework assignments can be computer-graded
  - More than 2000 problems and exercises from book included
- All problems can be turned into multiple-choice exam problems
- System used in many countries by over 100 universities
  - Completely free
  - Spanish language interface available

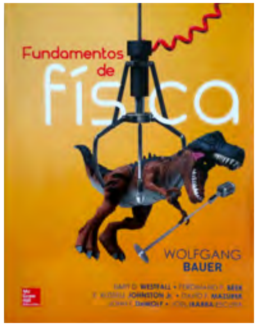
Summary

- The 21st century will see the integration of physics principles into the investigation of biology and environmental science
- We need to and can help our students be part of this revolution!









Email: bauer@pa.msu.edu