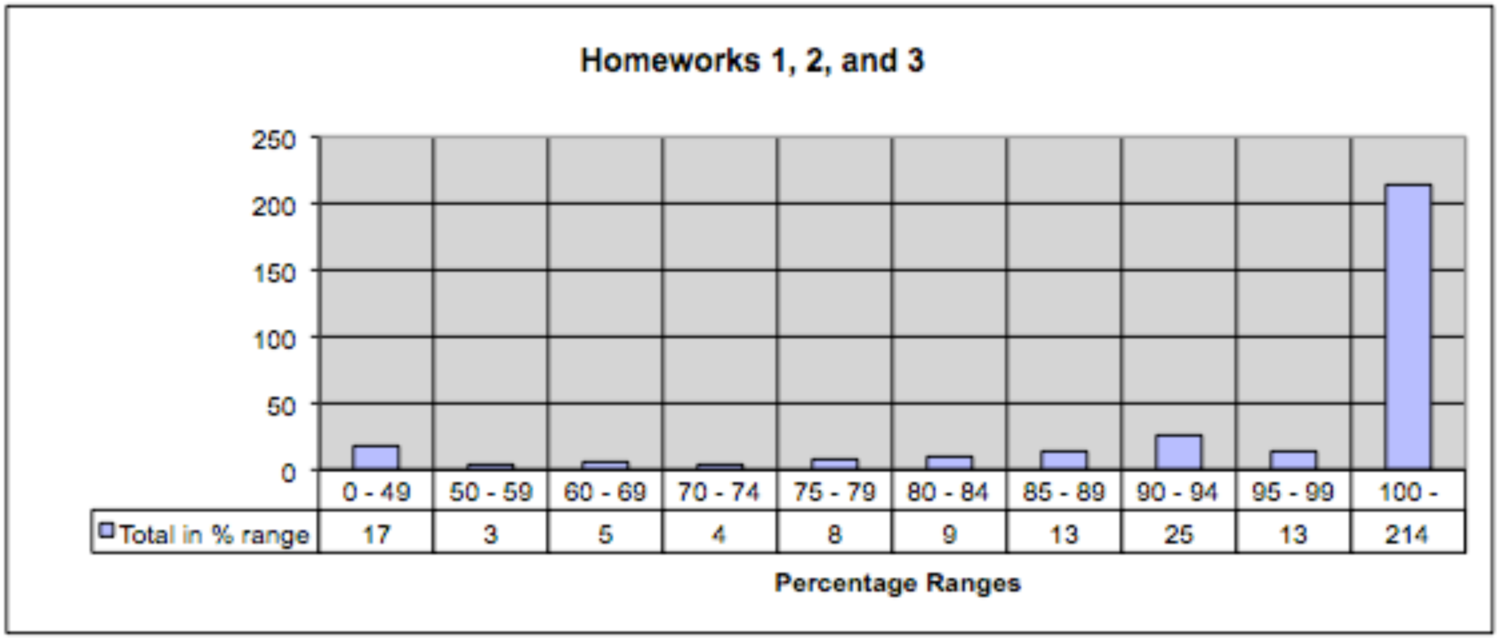
Physics 5D - Lecture 5 - Oct 28, 2013

Reminders:

Midterm Exam here next Monday Nov 4

Practice Midterm: physics.ucsc.edu/~joel/Phys5D

Review Lecture here Friday Nov 1 5 pm



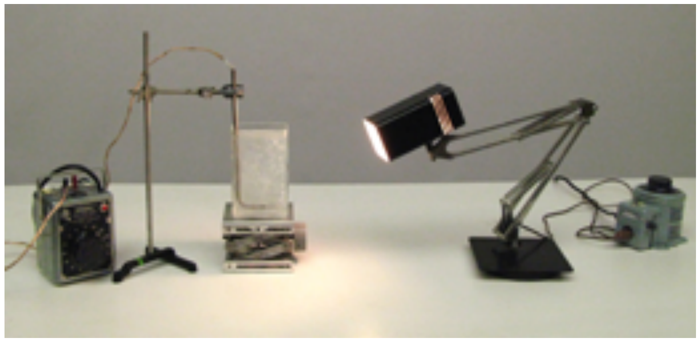
	0 - 49	50 - 59	60 - 69	70 - 74	75 - 79	80 - 84	85 - 89	90 - 94	95 - 99	100 -
Total in % range	17	3	5	4	8	9	13	25	13	214

Physics 5D - Lecture 5 - Oct 28, 2013

Convection, Radiation, Conduction
2nd Law of Thermodynamics

Demonstrations:

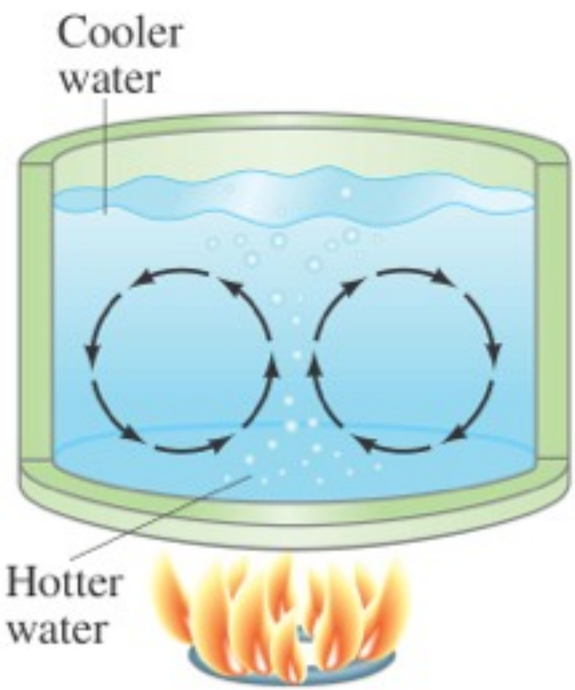
Convection

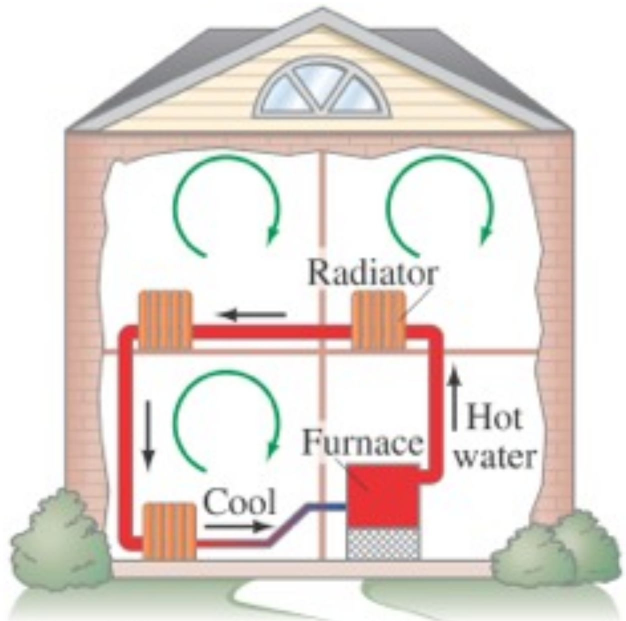


Beam of Cold

19-10 Heat Transfer: Convection, Radiation, Conduction

Convection occurs when heat flows by the mass **movement** of molecules from one place to another. It may be **natural** or **forced**; both these examples are natural convection.





19-10 Heat Transfer: Conduction, Radiation, Convection

Radiation is the form of energy transfer we receive from the Sun; if you stand close to a fire, most of the heat you feel is radiated as well.

The **energy** radiated has been found to be proportional to the **fourth** power of the temperature:

$$\frac{\Delta Q}{\Delta t} = \epsilon \sigma A T^4.$$

The constant σ is called the **Stefan-Boltzmann** constant:

$$\sigma = 5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}.$$

Heat Transfer by Radiation

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The constant σ is called the **Stefan-Boltzmann constant:**

$$\sigma = 5.67 \times 10^{-8}\,\mathrm{W/m^2 \cdot K^4}.$$

The **emissivity** ϵ is a number between 0 and 1 characterizing the surface; black objects have an emissivity near 1, while shiny ones have an emissivity near 0. It is the same for absorption; a good emitter is also a good absorber.

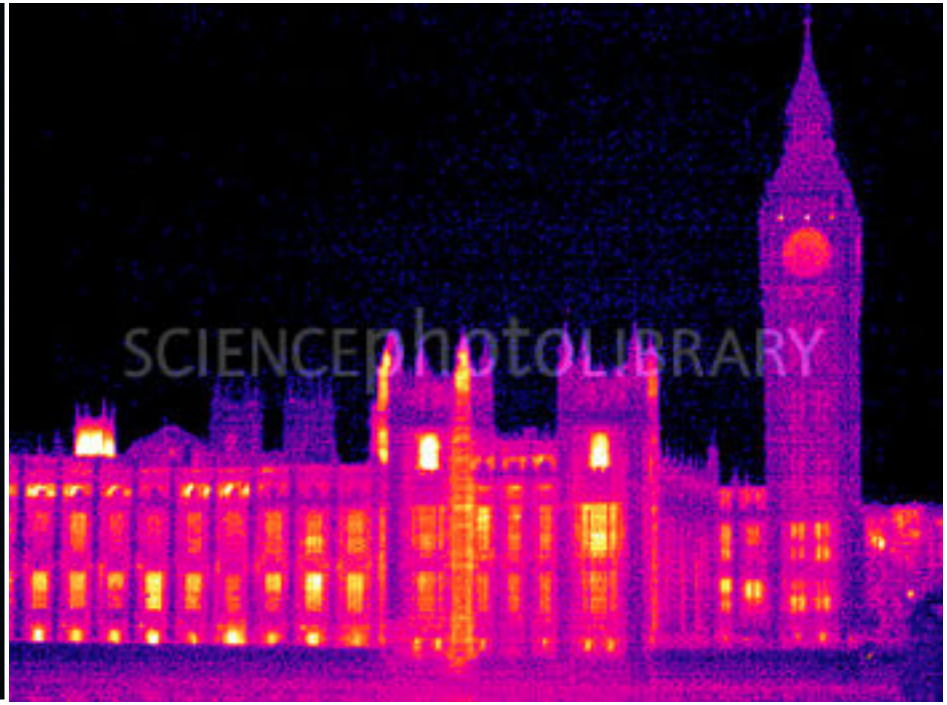
Heat Transfer by Radiation

Thermography—the detailed measurement of radiation from the body—can be used in medical imaging. Warmer areas may be a sign of **tumors** or **infection**; cooler areas on the skin may be a sign of **poor** circulation.

Heat Transfer by Radiation

Thermography can also be used to see where buildings are losing heat.

Thermogram showing heat loss from a house.



Thermogram of Houses of Parliament, London. The colours show variations in temperature. The scale runs from white (warmest), through yellow, orange, red and purple to black (coldest).

Heat Transfer by Radiation

Example 19-14: Cooling by radiation.

An athlete is sitting unclothed in a locker room whose dark walls are at a temperature of 15°C. Estimate his rate of heat loss by radiation, assuming a skin temperature of 34°C and ϵ = 0.70. Take the surface area of the body not in contact with the chair to be 1.5 m^2.

Heat Transfer by Radiation

Example 19-14: Cooling by radiation.

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Answer: let $T_1 = 34°\text{C} = 307\text{K},\ T_2 = 15°\text{C} = 288\text{K}$

$$\frac{\Delta Q}{\Delta t} = \epsilon \sigma A\,(T_1^4 - T_2^4),\ \text{where}\ \sigma = 5.67 \times 10^{-8}\,\text{W/m}^2\cdot\text{K}^4.$$

$$= (0.70)(5.67\text{x}10^{-8}\ \text{W/m}^2\text{K}^4)(1.5\text{m})^2\,(T_1^4 - T_2^4)$$

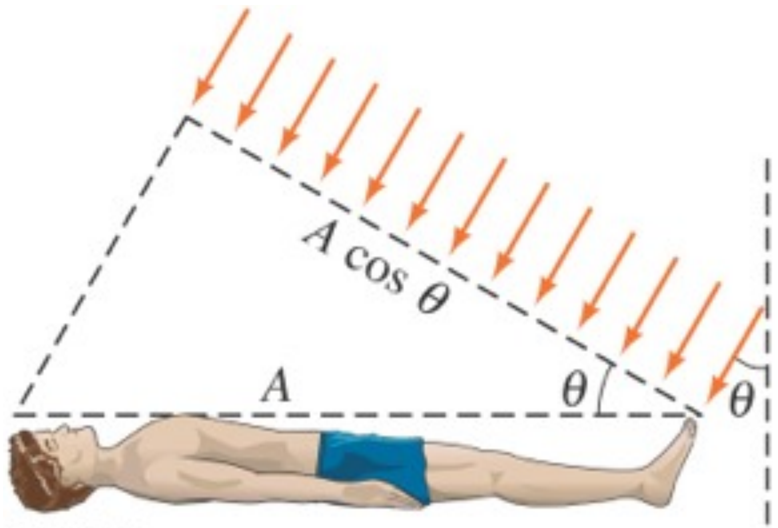
$$= 120\ \text{W}$$

This is greater than the ~100W that a resting person generates, so athlete loses heat quickly!

Heat Transfer by Radiation

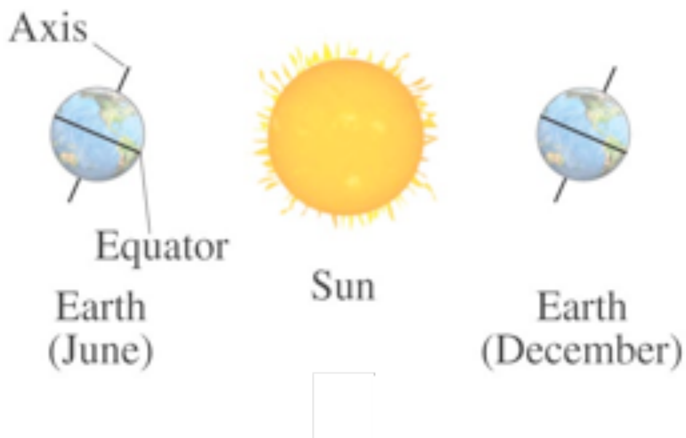
If you are in the **sunlight**, the Sun's radiation will warm you. In general, you will not be perfectly perpendicular to the Sun's rays, and will absorb energy at the rate:

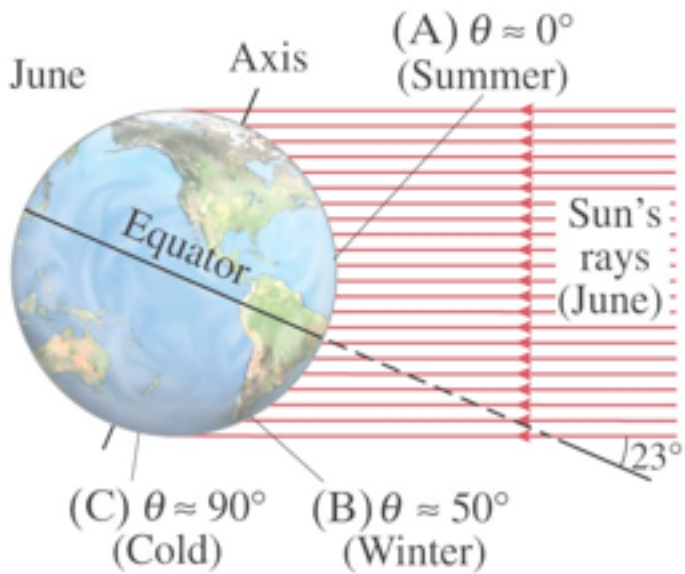
$$\frac{\Delta Q}{\Delta t} = (1000\ \mathrm{W/m^2})\,\epsilon A \cos\theta.$$



Heat Transfer by Radiation

This cos θ effect is also responsible for the seasons.





Heat Transfer by Radiation

Example 19-15: Star radius.

The giant star Betelgeuse emits radiant energy at a rate 10^4 times greater than our Sun, whereas its surface temperature is only half (2900 K) that of our Sun. Estimate the radius of Betelgeuse, assuming $\epsilon = 1$ for both. The Sun's radius is r_S = 0.7 Mkm.

Heat Transfer by Radiation

Example 19-15: Star radius.

The giant star Betelgeuse emits radiant energy at a rate 10^4 times greater than our Sun, whereas its surface temperature is only half (2900 K) that of our Sun. Estimate the radius of Betelgeuse, assuming $\epsilon = 1$ for both. The Sun's radius is r_S = 0.7 Mkm.

Answer: $\frac{\Delta Q}{\Delta t} = \epsilon \sigma A T^4$, and $T_B{}^4 = (1/16)\ T_S{}^4$

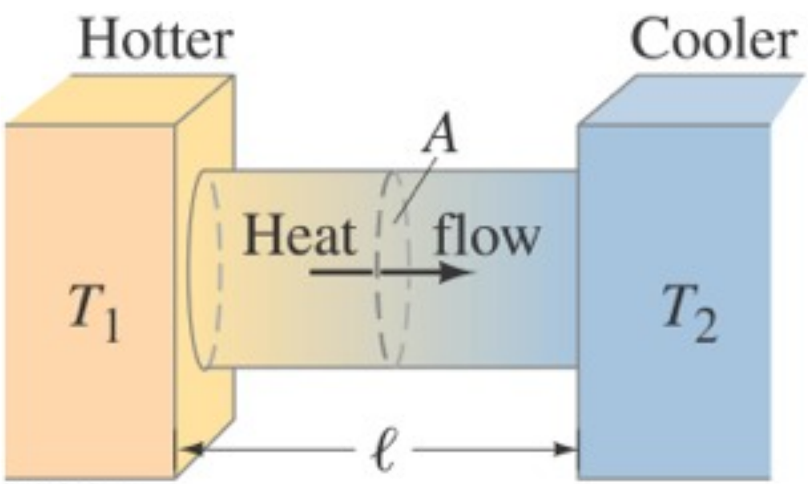
so $(R_B/R_S)^2 = 16 \times 10^4$ since the areas are proportional to R^2. Thus the radius of Betelgeuse $R_B = 400\ R_S$ = 300 Mkm, twice the distance of the earth from the sun!

19-10 Heat Transfer: Convection, Radiation, Conduction

Heat **conduction** can be visualized as occurring through molecular **collisions**.

The **heat flow** per unit time is given by:

$$\frac{\Delta Q}{\Delta t} = kA\frac{T_1 - T_2}{\ell}.$$



19-10 Heat Transfer: Conduction

TABLE 19–5
Thermal Conductivities

Substance	Thermal conductivity, k $\frac{\text{kcal}}{(\text{s}\cdot\text{m}\cdot\text{C}^\circ)}$	Thermal conductivity, k $\frac{\text{J}}{(\text{s}\cdot\text{m}\cdot\text{C}^\circ)}$
Silver	10×10^{-2}	420
Copper	9.2×10^{-2}	380
Aluminum	5.0×10^{-2}	200
Steel	1.1×10^{-2}	40
Ice	5×10^{-4}	2
Glass	2.0×10^{-4}	0.84
Brick	2.0×10^{-4}	0.84
Concrete	2.0×10^{-4}	0.84
Water	1.4×10^{-4}	0.56
Human tissue	0.5×10^{-4}	0.2
Wood	0.3×10^{-4}	0.1
Fiberglass	0.12×10^{-4}	0.048
Cork	0.1×10^{-4}	0.042
Wool	0.1×10^{-4}	0.040
Goose down	0.06×10^{-4}	0.025
Polyurethane	0.06×10^{-4}	0.024
Air	0.055×10^{-4}	0.023

The constant k is called the **thermal conductivity**.

Materials with large k are called **conductors**; those with small k are called **insulators**.

Notice that good electrical conductors are also good heat conductors. (That's because the free electrons can carry heat.)

19-10 Heat Transfer: Conduction

Given your experience of what feels colder when you rest your hand on it, which of the following surfaces would have the *highest thermal conductivity?*

A) a rug
B) a steel surface
C) a concrete floor
D) has nothing to do with thermal conductivity

19-10 Heat Transfer: Conduction

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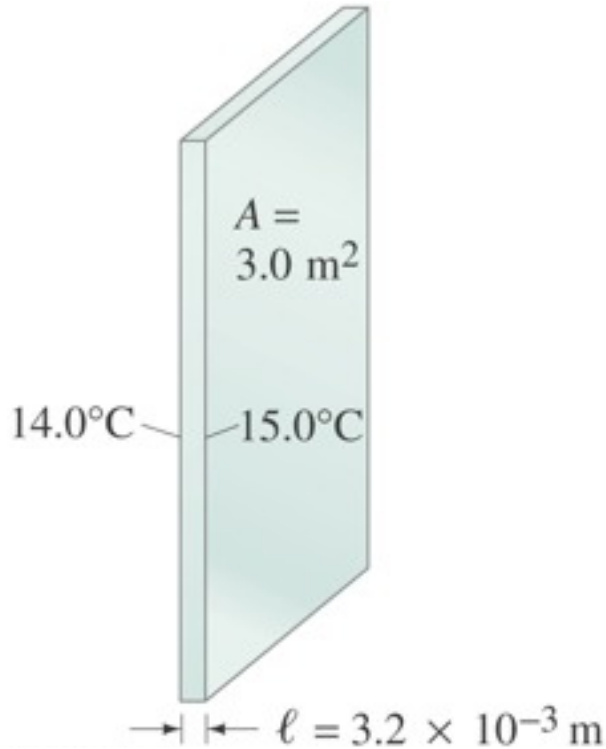
A) a rug
B) a steel surface
C) a concrete floor
D) has nothing to do with thermal conductivity

The heat flow rate is $k A (T_1 - T_2)/\ell$. Bigger k leads to bigger heat loss. From the table: Steel = 40, Concrete = 0.84, Human tissue = 0.2, Wool = 0.04, in units of J/(*s*.*m*.C°).

19-10 Heat Transfer: Conduction, Convection, Radiation

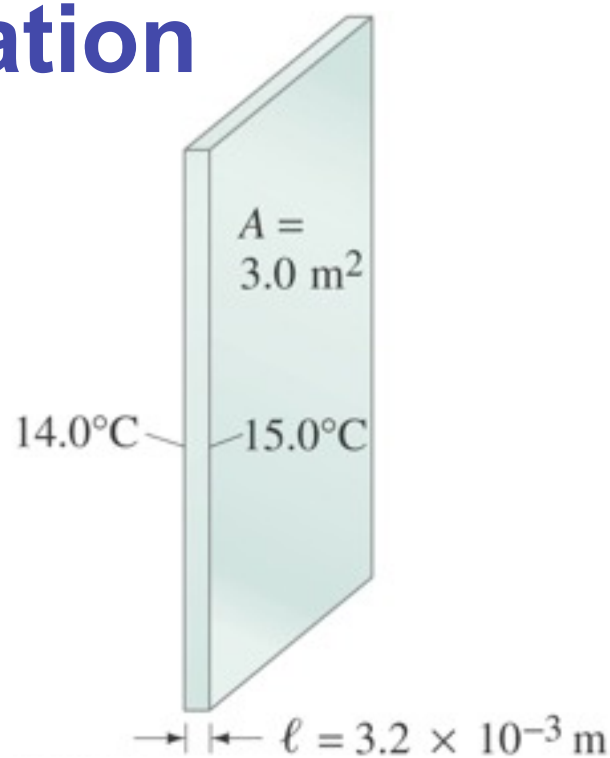
Example 19-13: Heat loss through windows.

A major source of heat loss from a house is through the windows. Calculate the rate of heat flow through a glass window 2.0 m x 1.5 m in area and 3.2 mm thick, if the temperatures at the inner and outer surfaces are 15.0°C and 14.0°C, respectively.



19-10 Heat Transfer: Conduction, Convection, Radiation

Calculate the rate of heat flow through a glass window 2.0 m x 1.5 m in area and 3.2 mm thick, if the temperatures at the inner and outer surfaces are 15.0°C and 14.0°C, respectively.



Answer:

Heat flow rate = $k A (T_1 - T_2)/\ell$

$= (2\text{x}10^{-4}\ \text{kcal/s/m/C°})(3\ \text{m}^2)(1\ \text{C°})/(3.2\text{x}10^{-3}\ \text{m})$

$= (0.6/3.2)\ \text{kcal/s} = 0.19\ \text{kcal/s}$

19-10 Heat Transfer: Conduction

Building materials are measured using ***R*-values** rather than thermal conductivity:

$$R = \ell/k.$$

Here, ℓ is the thickness of the material.

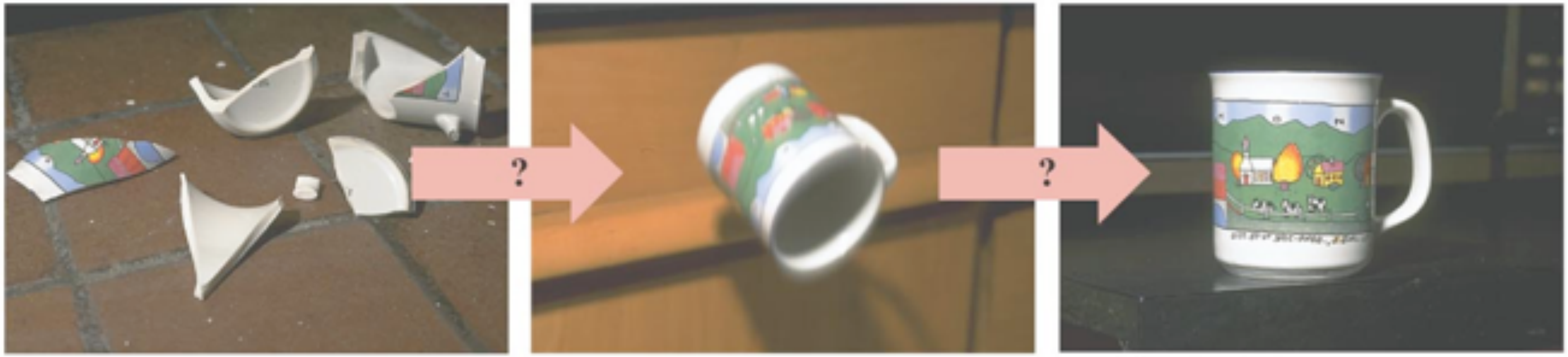
TABLE 19–6 *R*-values

Material	Thickness	*R*-value ($ft^2 \cdot h \cdot F°/Btu$)
Glass	$\frac{1}{8}$ inch	1
Brick	$3\frac{1}{2}$ inches	0.6–1
Plywood	$\frac{1}{2}$ inch	0.6
Fiberglass insulation	4 inches	12

In coastal California, the building code requires R-30 attic insulation, which is equivalent to 10” of fiberglass insulation.

Chapter 20
Second Law of Thermodynamics

20-1 The Second Law of Thermodynamics—Introduction



Initial state. Later: cup reassembles and rises up. Later still: cup lands on table.

The first law of thermodynamics tells us that energy is conserved. However, the absence of the process illustrated above indicates that conservation of energy is not the whole story. If it were, movies run backwards would look perfectly normal to us!

20-1 The Second Law of Thermodynamics—Introduction

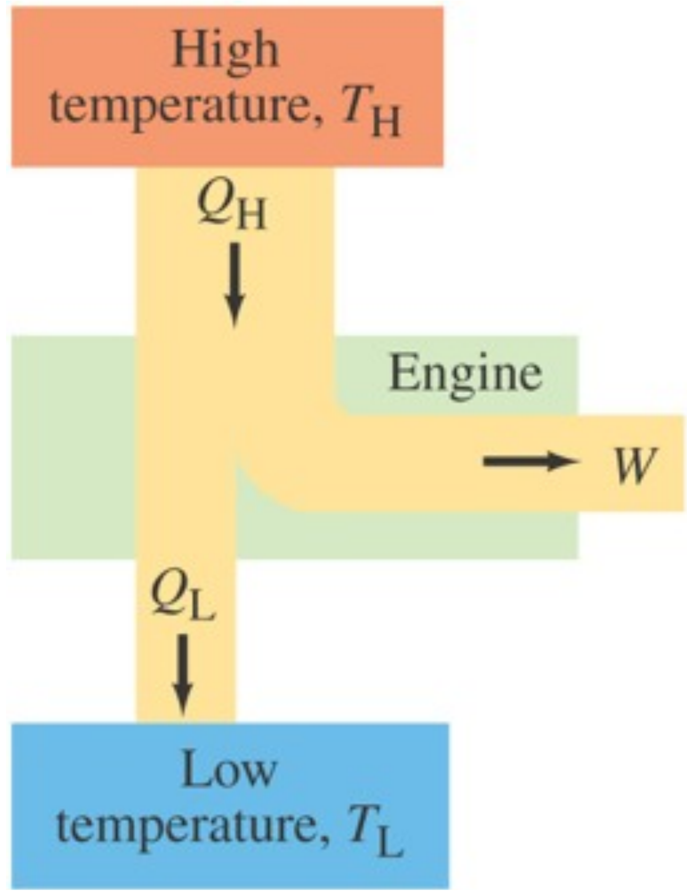
The second law of thermodynamics is a statement about which processes occur and which do not. There are many ways to state the second law; here is one:

Heat can flow spontaneously from a hot object to a cold object; it will not flow spontaneously from a cold object to a hot object.

20-2 Heat Engines

It is easy to produce thermal energy using work, but how does one produce work using thermal energy?

This is a heat engine; mechanical energy can be obtained from thermal energy only when heat can flow from a higher temperature to a lower temperature.



20-2 Heat Engines

We will discuss only engines that run in a repeating cycle; the change in internal energy over a cycle is zero, as the system returns to its initial state.

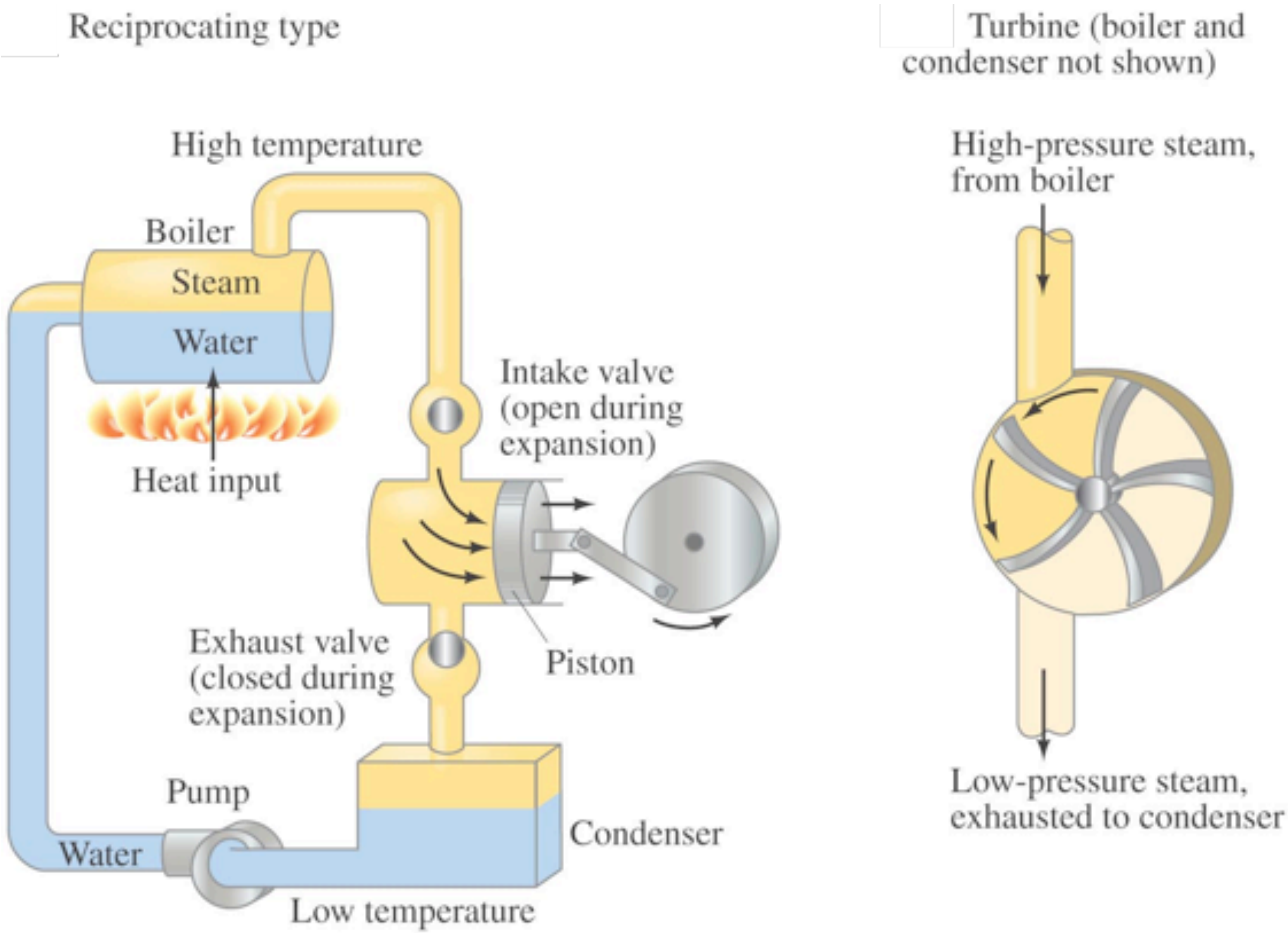
The high-temperature reservoir transfers an amount of heat Q_H to the engine, where part of it is transformed into work W and the rest, Q_L, is exhausted to the lower temperature reservoir. Thus

$$W = Q_H - Q_L$$

Note that all three of these quantities are positive.

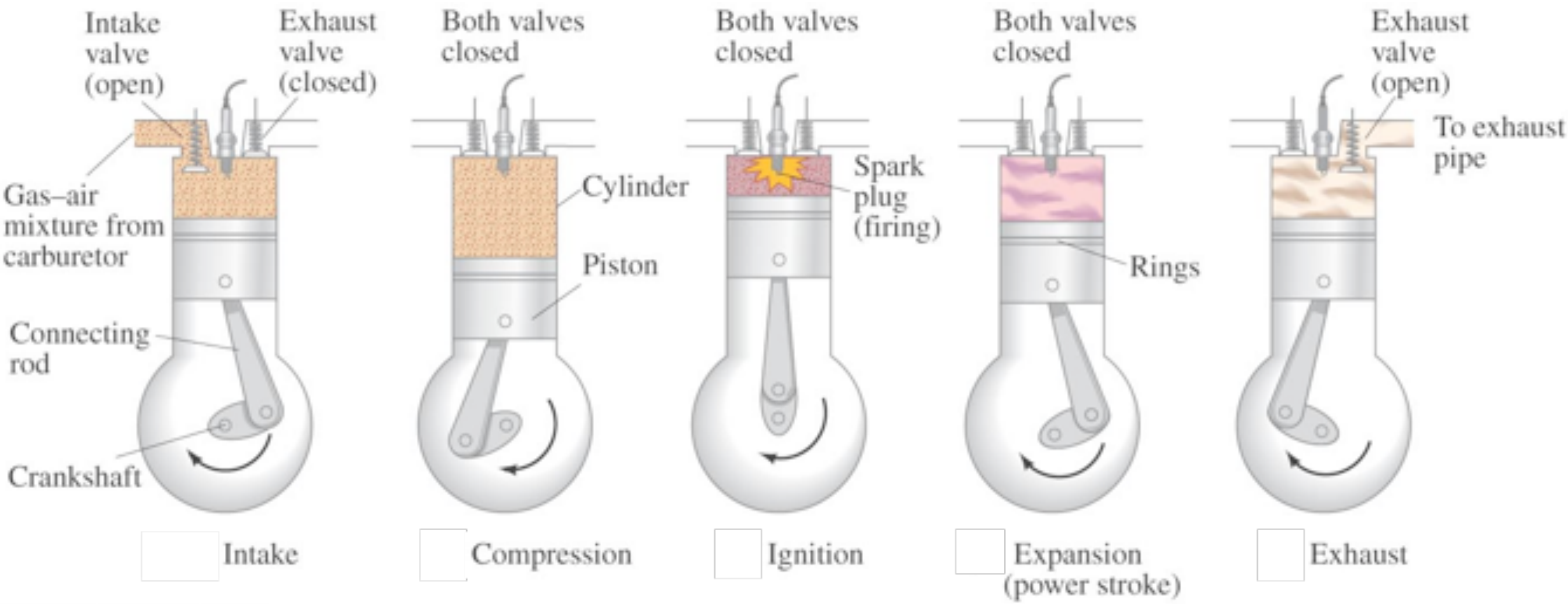
20-2 Heat Engines

A steam engine is one type of heat engine.



20-2 Heat Engines

The internal combustion engine is a type of heat engine as well.



20-2 Heat Engines

Why does a heat engine need a temperature difference?

Otherwise the work done on the system in one part of the cycle would be equal to the work done by the system in another part, and the net work would be zero.

$$W = Q_{\mathrm{H}} - Q_{\mathrm{L}}$$

20-2 Heat Engines

The **efficiency** of the heat engine is the ratio of the work done to the heat input:

$$e = \frac{W}{Q_H}.$$

Using conservation of energy to eliminate W, we find:

$$e = \frac{W}{Q_H}$$

$$= \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}.$$

20-2 Heat Engines

Example 20-1: Car efficiency.

An automobile engine has an efficiency of 20% and produces an average of 23 kJ of mechanical work per second during operation. Remember: $Q_H = W/e$.

(a) How much heat input is required, and

(b) How much heat is discharged as waste heat from this engine, per second?

20-2 Heat Engines

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(a) How much heat input is required, and

$$Q_H = W/e = 23\ \text{kJ}/0.20 = 115\ \text{kJ}$$

(b) How much heat is discharged as waste heat from this engine, per second?

$$Q_L = (1\text{-}e)\ Q_H = (0.8)\ 115\ \text{kJ} = 92\ \text{kJ}$$

20-2 Heat Engines

No heat engine can have an efficiency of 100%. This is another way of writing the second law of thermodynamics:

No device is possible whose sole effect is to transform a given amount of heat completely into work.