

Preview of Period 6: Entropy and the Laws of Thermodynamics

6.1 Conservation of Energy and the 1st Law of Thermodynamics

What is the 1st Law of Thermodynamics?

6.2 Order, Disorder and Entropy

What is entropy? Why does it increase?

6.3 Equilibrium and the 2nd Law of Thermodynamics

Why do systems go toward equilibrium?

6.4 Reversible Process and Perpetual Motion

What is an irreversible system?

Is perpetual motion possible?

6.5 Efficiency and Irreversible Processes

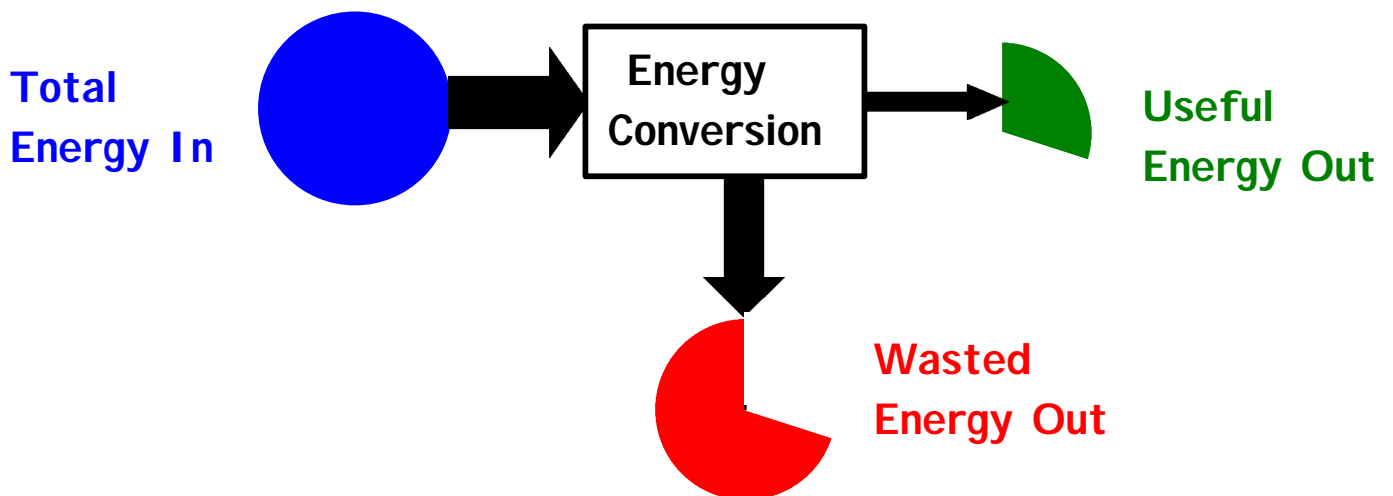
How do steam engines work?

How do air conditioners work?

What is a heat pump?

The law of conservation of energy:

- ◆ Energy can be neither created nor destroyed.
- ◆ The total amount of energy we have now in the Universe is the same amount that existed at its beginning.
- ◆ All the energy that goes into a conversion process must come out.
- ◆ In every energy conversion, some energy is wasted, often in the form of thermal energy.
- ◆ When applied to thermodynamic systems, the law of conservation of energy is called the **first law of thermodynamics**.



How is energy conserved by the rolling carts?

First Law of Thermodynamics

The change in internal energy of a system DU equals the heat Q added to or subtracted from the system minus the work W done by the system

$$DU = Q - W$$

U = total internal energy (joules)

DU = the change in internal energy (joules)

Q = heat added to or subtracted from the system (joules)

W = work done by the system (joules)

- **Total internal energy** is the kinetic energy of the molecules plus the potential energy stored in molecular attractions.
- It is not possible to get more energy out of a system than is put into the system!

Act 6.2: Ordered and Disordered Checkers

R	R
R	R

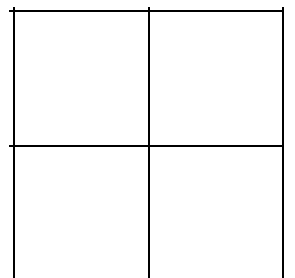
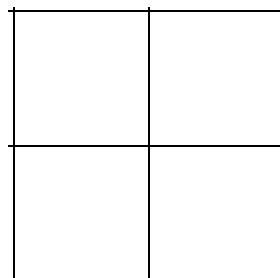
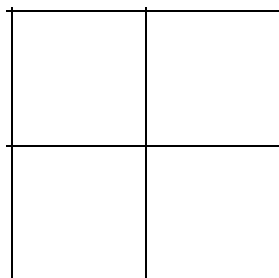
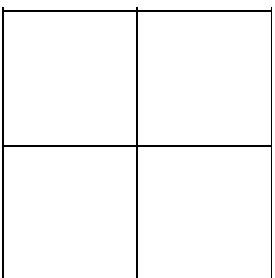
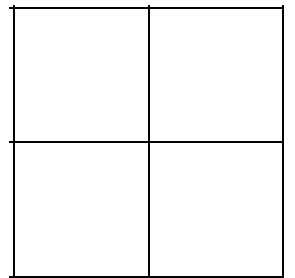
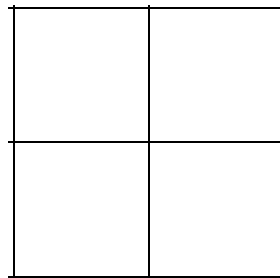
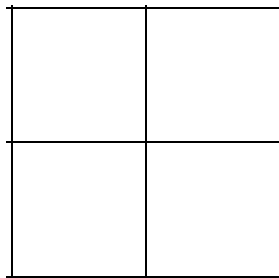
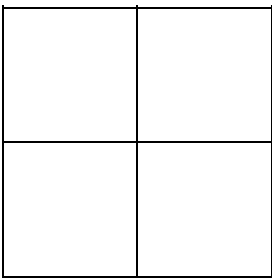
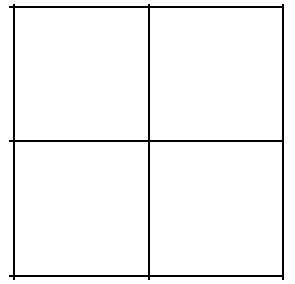
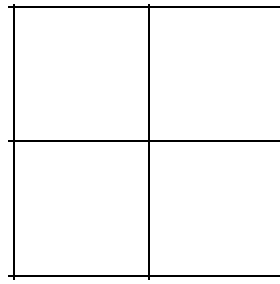
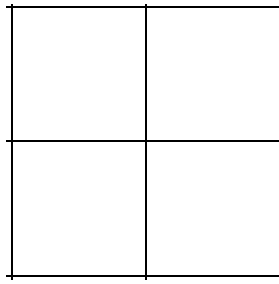
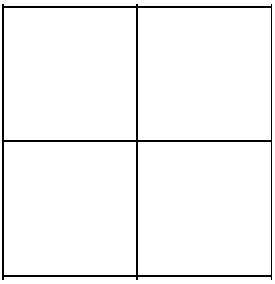
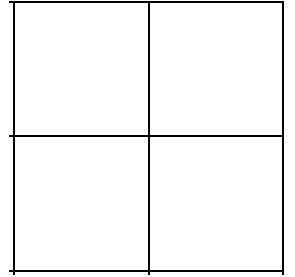
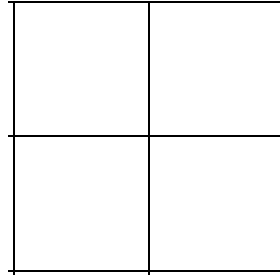
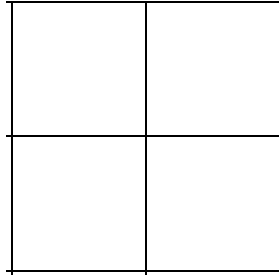
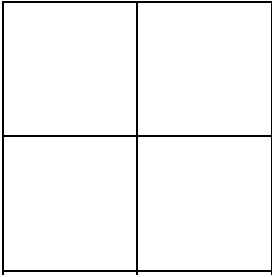
R	B
R	R

R	R
B	R

R	R
R	B

R	R
B	B

Act 6.2: Ordered and Disordered Checkers



Act 6.2: Ordered and Disordered Checkers

R	R
R	R

R	B
R	R

R	R
B	R

R	R
R	B

R	R
B	B

B	R
R	R

B	R
R	B

R	B
B	R

B	B
R	R

R	B
R	B

B	R
B	R

R	B
B	B

B	B
R	B

B	B
B	R

B	R
B	B

B	B
B	B

Entropy (Disorder) and the 2nd Law of Thermodynamics

- ◆ Entropy is the measure of degree of order or disorder of a system.
- ◆ The greater the disorder, the greater the entropy
- ◆ Order and disorder are always described in relation to a set of rules or property.
- ◆ In most physical situations there are more disordered than ordered states.
- ◆ The entropy (disorder) of the Universe always increases.
- ◆ To reduce the entropy of a system, work must be done on that system.

The Entropy Story so far ...

- ◆ **Entropy** is a measure of the degree of disorder of a system.
- ◆ The greater the disorder, the greater the amount of entropy.
- ◆ In nature, disordered systems are more common than ordered systems because there are many more disorderly arrangements than orderly arrangements.
- ◆ Entropy tends to increase with time.

If the temperature is constant, the change in entropy is given by

$$DS = DQ/T$$

The **first law of thermodynamics** states the change in internal energy of a system equals the heat added to the system minus the work done by the system.

$$DU = Q - W$$

Equilibrium

- A system, when left undisturbed, progresses toward equilibrium with its surroundings.

For example, ice melts at room temperature.

The melted water warms until it reaches room temperature.

- The entropy of a system that is in equilibrium with its surroundings remains constant because the system has already reached its maximum entropy.
- As systems move toward equilibrium, they can give off energy or do work or do both.
- To change a system from its equilibrium state requires that work be done on the system or that energy be added to the system or both.

The 2nd Law of Thermodynamics

The second law of thermodynamics can be stated in several ways:

- 1) The entropy of a physical system left to itself will **increase** or, if the system is already at its maximum entropy, the entropy will remain the same.
- 2) Any system, when left to itself, tends toward equilibrium with its surroundings.
- 3) The entropy of a system that is in equilibrium with its surroundings remains constant.
- 4) All physical processes are irreversible.
 - ◆ Processes are irreversible if energy must be added or work be done or both to return the system to its original state.

Is perpetual motion possible?

Heat Engines

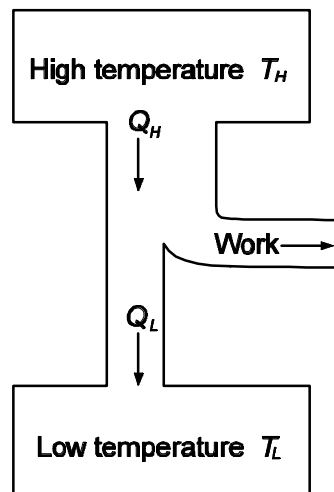
Heat engines do work by converting thermal energy into mechanical energy.

The efficiency of an ideal heat engine =

$$Eff = \frac{T_H - T_L}{T_H}$$

Note: the temperatures T are measured in Kelvin

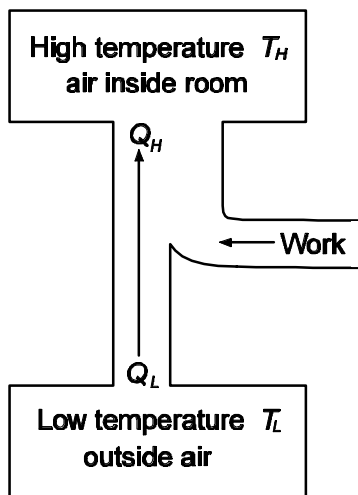
Diagram of a Heat Engine



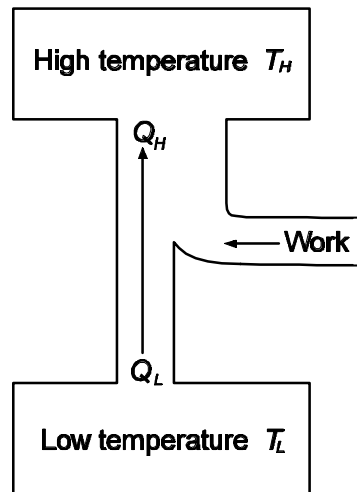
Heat Pumps, Air Conditioners, and Refrigerators

These devices use energy to move heat from cooler environments to warmer environments.

A Heat Pump



An Air Conditioner or Refrigerator



Coefficient of Performance of Heat Pumps, Air Conditioners, and Refrigerators

The efficiency of the process of moving heat from cooler environments to warmer environments. is measured by the coefficient of performance, *COP*

$$\text{Heat pump COP} = \frac{Q_H}{W} = \frac{T_H}{T_H - T_C}$$

where Q_H = heat transferred from a lower temperature environment to a higher temperature environment

Air Conditioner or refrigerator COP =

$$\frac{Q_L}{W} = \frac{T_C}{T_H - T_C}$$

where Q_L = heat transferred from a lower temperature environment to a higher temperature environment.

***T* is measured in Kelvin**

Period 6 Summary

6.1: An ordered system conforms to a predetermined set of rules.

In nature, disordered systems are more common than ordered systems because there are many more disorderly arrangements than orderly arrangements.

Entropy is a measure of the degree of disorder of a system.

The greater the disorder, the greater the amount of entropy.

If the temperature is constant, the change in entropy is given by

$$DS = DQ/T$$

Entropy tends to increase with time. For example, ice melts at room temperature or metal rusts when exposed to moisture.

6.2: The **first law of thermodynamics** states the change in internal energy of a system equals the heat added to the system minus the work done by the system.

$$DU = Q - W$$

Period 6 Summary, Continued

6.3: The second law of thermodynamics can be stated in several ways:

- 1) The entropy of a physical system left to itself will increase or, if the system is already at its maximum entropy, the entropy will remain the same.
- 2) Any system, when left to itself, tends toward equilibrium with its surroundings.
- 3) The entropy of a system that is in equilibrium with its surroundings remains constant.
- 4) All physical processes are irreversible.

6.4: As systems move toward equilibrium, they can give off energy or do work or do both. To change a system from its equilibrium state requires that work be done on the system or that energy be added to the system or both .

Physical changes are irreversible if energy must be added or work be done or both to return the system to its original state.

Period 6 Summary, Continued

6.5 Heat engines do work by converting thermal energy into mechanical energy.

The efficiency of an ideal heat engine =

$$Eff = \frac{T_H - T_L}{T_H} \quad \text{with } T \text{ measured in Kelvin}$$

Heat pumps, refrigerators, and air conditioners use energy to move heat from cooler environments to warmer environments.

The efficiency of the process is measured by the coefficient of performance, *COP*

Heat pump: $COP = Q_H/W$

where Q_H = heat transferred from a lower temperature environment to a higher temperature environment

Air Conditioner or refrigerator:

$$COP = Q_L/W$$

where Q_L = heat transferred from a lower temperature environment to a higher temperature environment.

Period 6 Review Questions

- R.1** An ice cube is dropped into a hot cup of coffee. As the ice cube melts, the coffee cools down. What happens to the entropy of the ice cube, the entropy of the coffee, and the entropy of the system as a whole?
- R.2** What is the difference between a heat pump and a heat engine?
- R.3** What is the difference between a heat pump and a refrigerator?
- R.4** Why are perpetual motion machines doomed to failure?
- R.5** Do you want the coefficient of performance *COP* of a refrigerator to be small or large?