Physics 221, April 5

Thermodynamics

Key Concepts:

- The first law
- Thermodynamic processes
- The second law
- Entropy

The first law of thermodynamics

Energy is conserved. $\Delta U = \Delta Q - \Delta W$.

U = internal energy of a system (ordered and disordered energy).

- A system can be anything (gas, liquid, solid).
- The internal energy can be in the form of kinetic energy (translational or rotational) and in the form of potential energy.
- The internal energy U can change, if the system interact with its environment.

ΔQ = heat flowing into the system.

- Heat can flow in or out of the system. ΔQ is negative if heat flows out of the system.

ΔW = work done by the system.

- Work can be done by the system on its environment or by external forces on the system. ΔW is negative if work is done on the system.

For an ideal gas, disordered internal energy U is proportional to the temperature T of the system.

It is possible to change the temperature of a system when the system is insulated from its surroundings, so that no heat can flow into and out of the system.

1. True
2. False

Hint:
$\Delta U = \Delta Q - \Delta W$
For an ideal gas
U is proportional to T.

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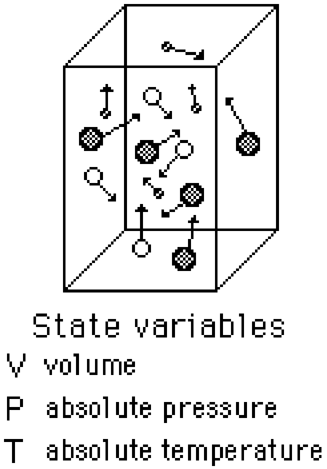
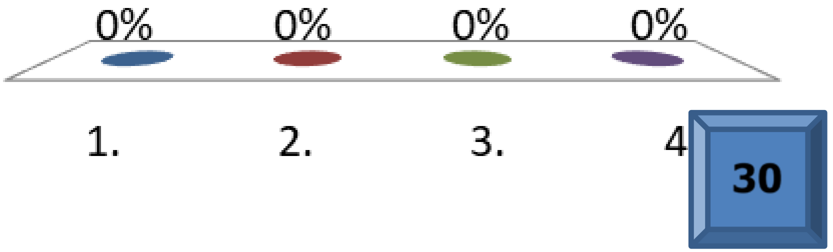
5 moles of a monatomic gas has its pressure increased from 10^5 Pa to $2*10^5$ Pa. This process occurs at a constant volume of 0.1 m^3. Determine the change in the internal energy of the gas.

Hint: $PV = nRT$, $U = (3/2)nRT$, $R = 8.31$ J/K



1. 10^4 J
2. 15000 J
3. 7500 J
4. The change in U depends on how the temperature was raised.



Physical properties

A physical property of a system in a given state can be measured.

N, U, V, P, and T are examples of physical properties of a gas system.

N = # of particles that make up a system

U = internal energy of the system

V = volume of the system

P = pressure of the system

T = temperature of the system

The physical properties depend only on the state of the system, not on the way the system was put into this state.

When a system changes from state 1 to state 2, ΔQ and ΔW depend on the process. They are not physical properties of the system.

Thermodynamic processes

Which processes can change the state of a system?

Restriction for all processes: $\Delta U = \Delta Q - \Delta W$ (first law of thermodynamics)

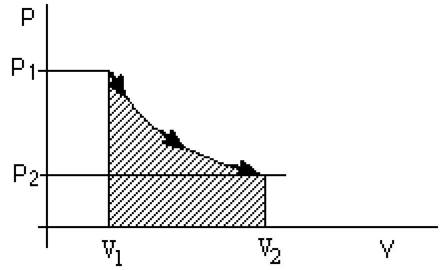
adiabatic process: No heat enters or leaves the system. $\Delta U = -\Delta W$

isobaric process: The pressure is constant. $\Delta W = P(V_2 - V_1)$ for an ideal gas.

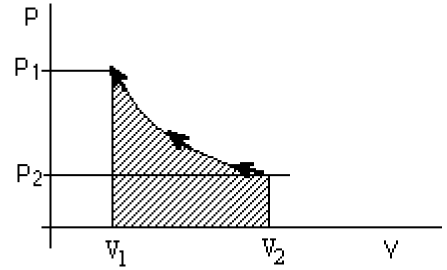
isometric process: The volume is constant. $\Delta W = 0$. (isovolumetric, isochoric)

isothermal process: The temperature is constant. $\Delta U = 0$ for an ideal gas.

The work done by or on a gas can be represented as the area under the curve on a PV diagram.



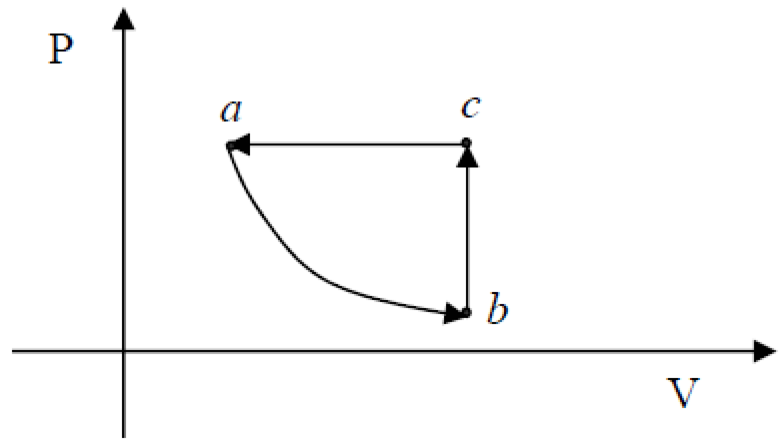
The system does positive work.

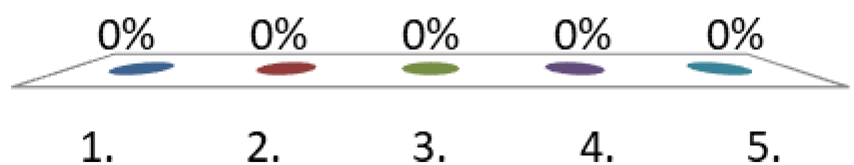


The system does negative work.

Consider the change a gas undergoes as it transitions from point c to point a in the PV diagram.   What type of process is this?

1. Adiabatic
2. Isothermal
3. Isobaric
4. Isochoric
5. none of the above





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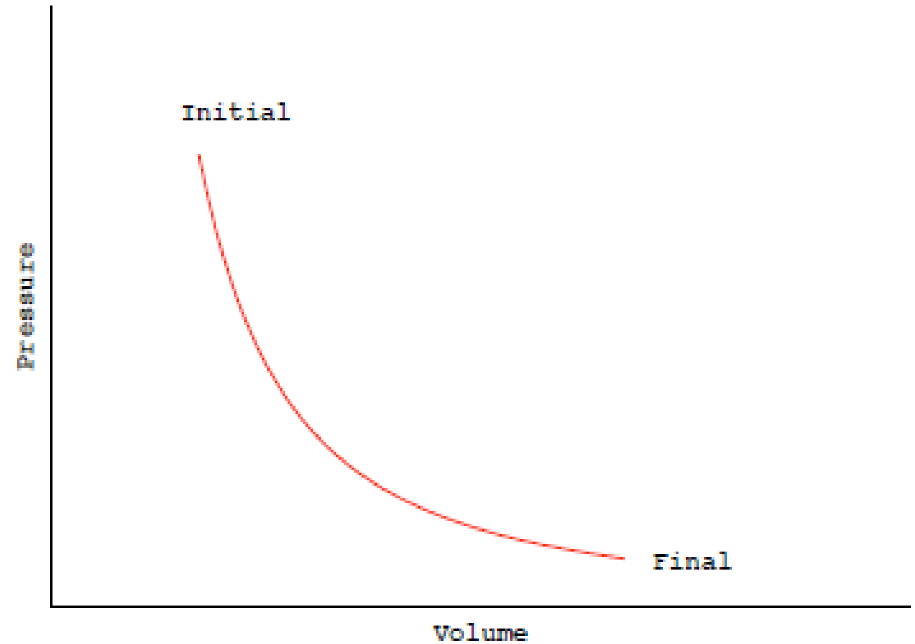
One mole of monatomic gas undergoes an adiabatic process (i.e. one where no heat enters or leaves the system). A pressure versus volume graph of the process is shown to the right. The initial and final volumes are given in the table below.

Ideal gas law: PV = nRT, R = 8.31 J/K

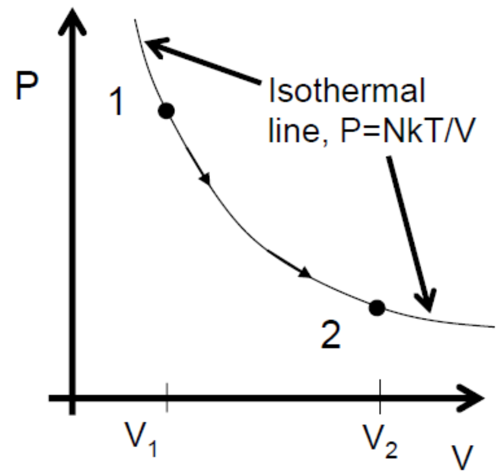


	Volume	Pressure
Initial	$0.01\ m^3$	3×10^5 Pa
Final	$0.04\ m^3$	0.3×10^5 Pa

What are the initial and final temperatures?

1. There is not enough information given to know.
2. The same, since no heat enters the system.
3. Initial T: 361 K; final T: 144 K
4. Initial T: 3000 K; final T: 1200 K

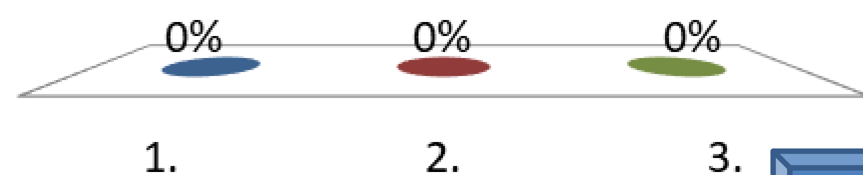
An ideal gas in a closed container with a piston lid is taken from thermodynamic state, 1, to a new thermodynamic state, 2, by an isothermal path as shown below in the P-V plane.



Let ΔU be the internal energy change during this process, ΔQ be the heat transferred into the gas, and ΔW be the work done by the gas.

Hint:
U is proportional to T.
ΔU = ΔQ - ΔW

1. ΔU is positive, ΔQ is positive and ΔW = 0
2. ΔU is negative, ΔQ is negative and ΔW = 0
3. ΔW is positive, ΔQ is positive and ΔU = 0



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The second law of thermodynamics

Heat cannot, of itself, flow from a cold to a hot object.

Can we transfer thermal energy from a cold to a hot object?

Yes, but it takes ordered energy. We must do work, converting some ordered energy into thermal energy. We then deliver more heat to the hot object than we remove from the cold object.

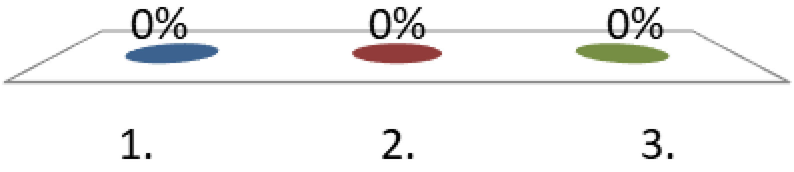
The minimum amount of work we must do is $W_{min} = Q_{hot} - Q_{cold}$, where

$$Q_{hot}/T_{hot} = Q_{cold}/T_{cold}.$$

Examples: refrigerator, air conditioner, heat pump

Is it possible to cool down a well insulated room on a hot summer day by leaving the refrigerator door open, and using the refrigerator as an air conditioner?

1. Yes
2. No
3. Only if it is a very large capacity refrigerator.



The second law of thermodynamics

Heat cannot be taken in at a certain temperature with no other change in the system or its environment and converted into work.

Can we do work with heat?

Yes, we can remove heat from a hot object and convert some of it into ordered energy, but only if we have some colder place to dump the rest of it.

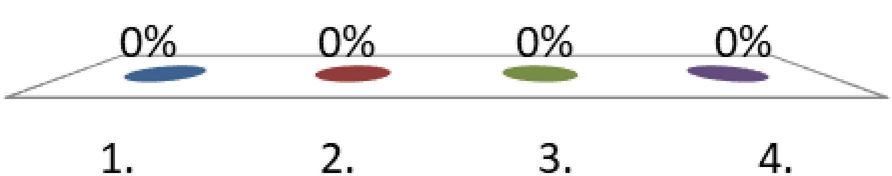
The maximum amount of work we can get is $W_{max} = Q_{hot} - Q_{cold}$, where

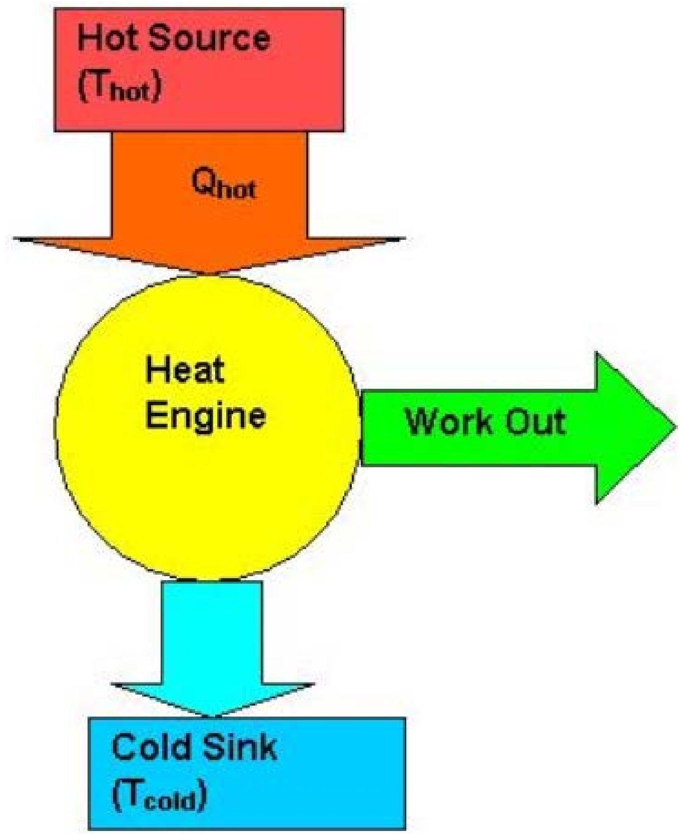
$$Q_{hot}/T_{hot} = Q_{cold}/T_{cold}.$$

Examples: steam engine, internal combustion engine, fossil and nuclear power plants

The _______ the temperature difference between hot and cold, the larger the fraction of heat you can divert and transform into __________.

1. larger; temperature
2. larger; work
3. smaller; work
4. smaller; temperature





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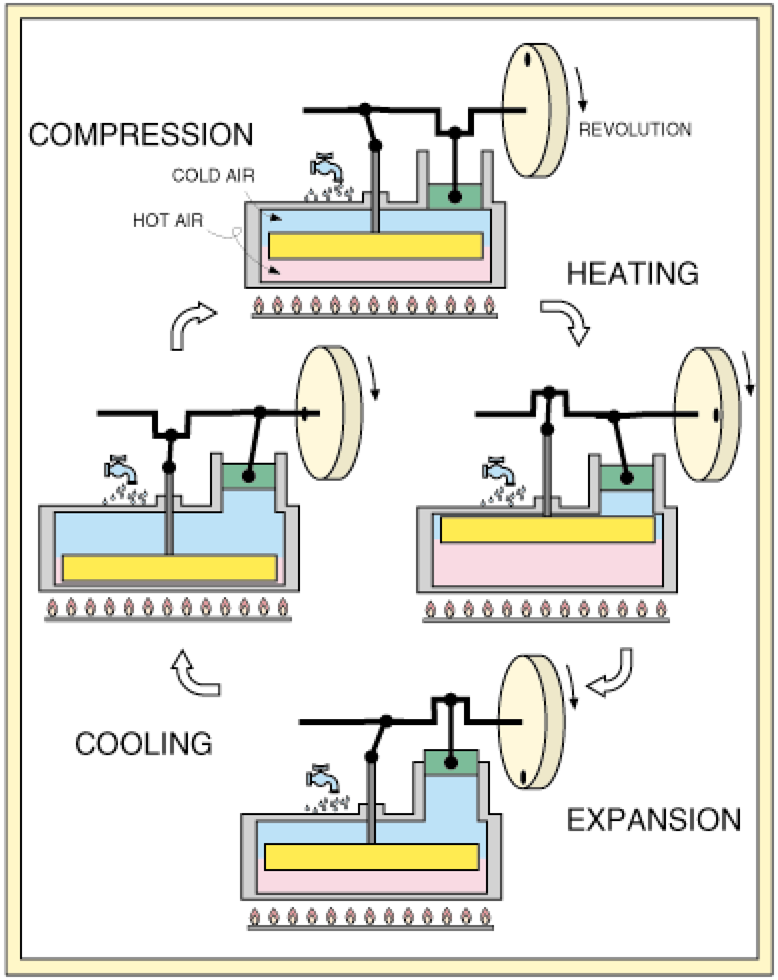
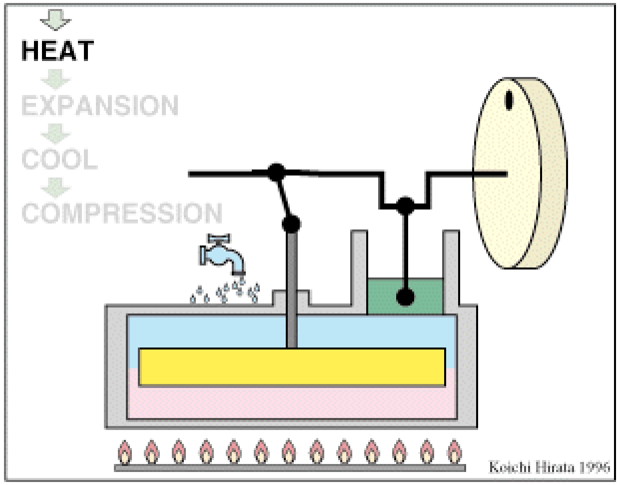
The Stirling engine (Demo)





Entropy

Why does heat, by itself, not flow from a cold object into a hot object?

Why is it impossible to convert thermal (disordered) energy completely into mechanical (ordered) energy?

Because disorder is more likely than order.

But how do we quantify and measure disorder?

We define a quantity called entropy which is a measure of disorder.

The entropy of a system changes when heat (disordered energy) enters or leaves the system.

Change of entropy in terms of heat: $\Delta S = \Delta Q/T$

(ΔS increases when disordered or thermal energy is added to the system.)

The total entropy of a closed system is always increasing is another way of stating the second law of thermodynamics.

Entropy

Entropy is also a measure of the variety of ways in which a closed system with a fixed amount of total energy can organize itself.

- The **macrostate** of a system is its state as viewed at a macroscopic level.
- The **microstate** of a system is its state as viewed at the molecular level.
- The **multiplicity Ω** is the number of ways the insides of a system can be arranged so that from the outside things looks the same.
- The **entropy S** is $S = k_B \ln\Omega$, where k_B is the Boltzmann constant.

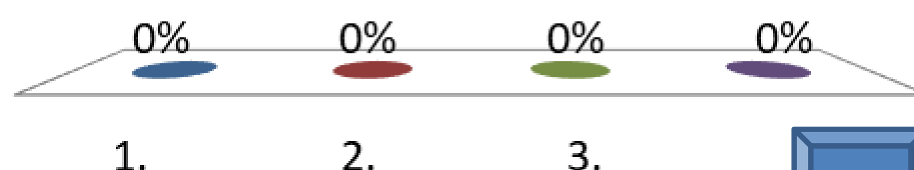
For a closed system all microstate are equally likely.

The macrostate with the largest multiplicity therefore is the most likely state.

Equilibrium is the most likely state and the equilibrium state has the highest entropy.

We flip a fair coin 10 times. Define a macrostate to be the number of heads. Which macrostate is most likely to occur?

1. 10 heads
2. 7 heads
3. 5 heads
4. 1 head



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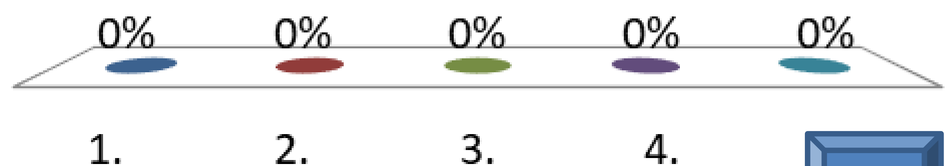
Two dice are thrown. Let the macrostate be the sum of the two numbers on the top faces. What is the multiplicity of the macrostate “4”?

1. 4
2. 6
3. 2
4. 3
5. 1



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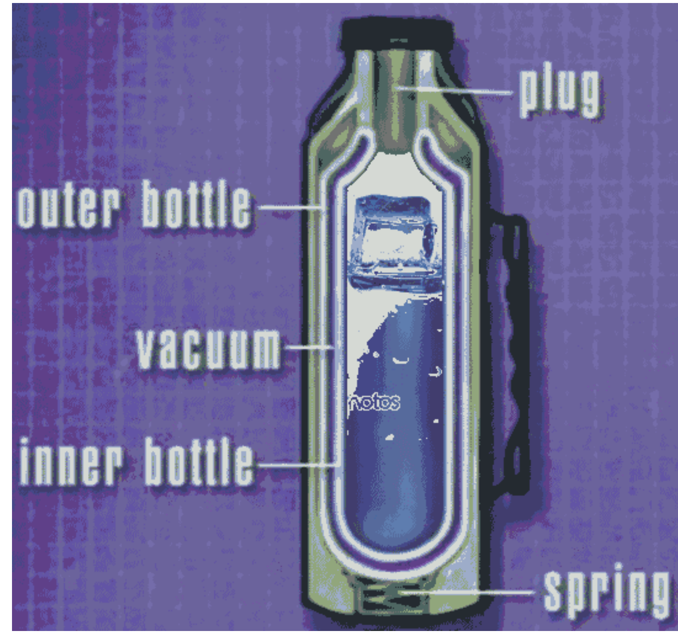
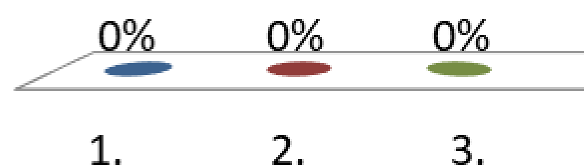
An ice cube is placed in a cup containing some liquid water. The water and ice exchange energy with each other but not with the outside world.

Consider the following possibility: After awhile, we find that the water has increased in temperature and ice has gotten colder.

Which statement is correct?



1. This process can satisfy the 1st law of thermodynamics and happens in nature.
2. This process violates the 1st law and does not happen in nature.
3. This process can satisfy the 1st law, but still does not happen in nature.
4. This process violates both the first and the 2nd law of thermodynamics.



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