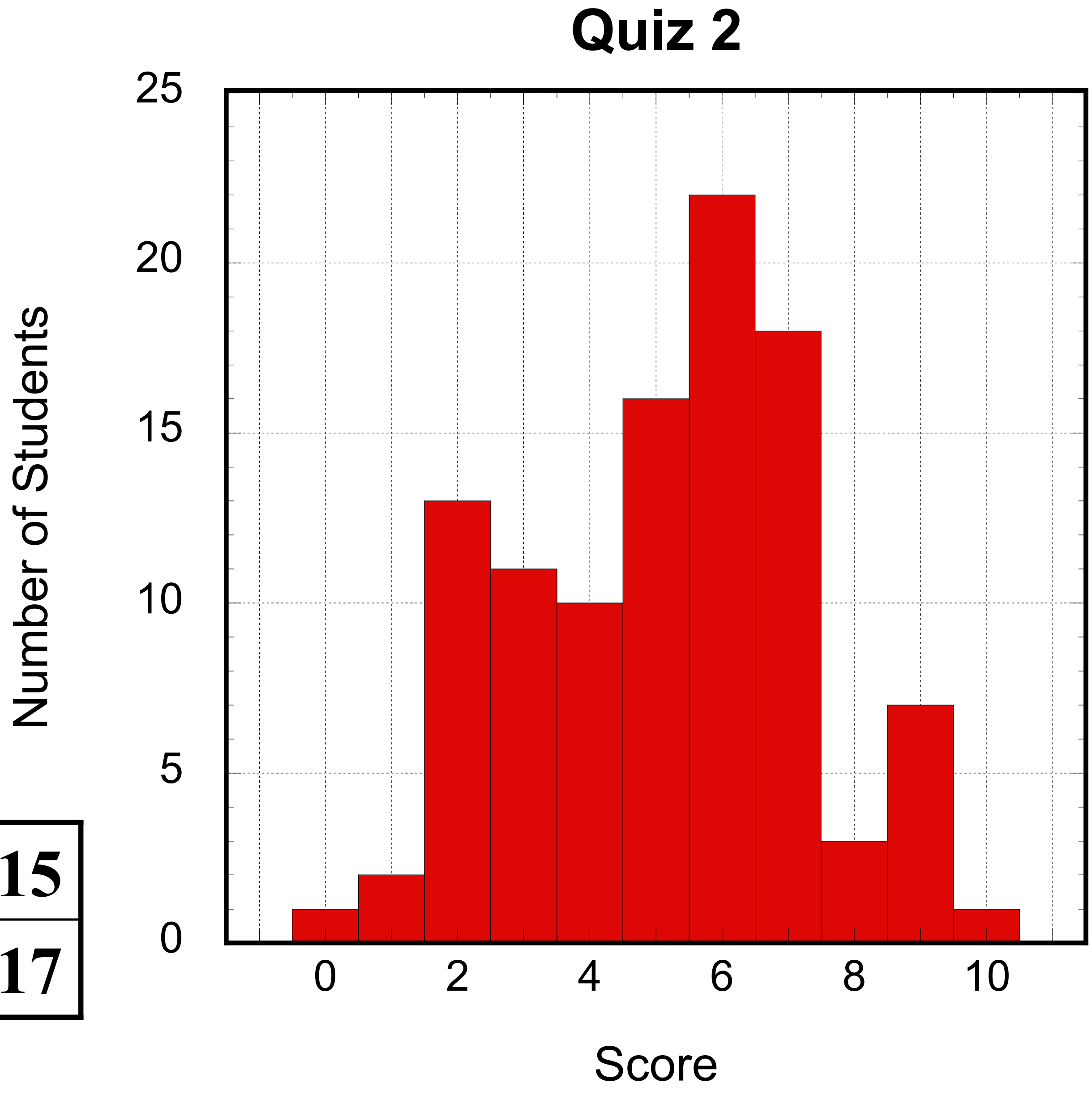
Physics 132- Fundamentals of Physics for Biologists II

Statistical Physics and Thermodynamics

QUIZ 2



AVG:	**5.15**
STDEV:	**2.17**

1. (4 pts) A 200 g block of copper at a temperature of 55 ^{o}C is put into an insulated beaker of water at 20 ^{o}C. The two come to thermal equilibrium at a temperature of about 30 ^{o}C – much closer to the original temperature of the water than of the copper. (From the macroscopic point of view, the specific heat of water is about 1.0 J/g-^{o}C while the specific heat of copper is only about 0.4 J/g-^{o}C.) However, from the microscopic point of view…

1.1 (2 pts) From this you can conclude

A. There are more degrees of freedom in 200 g of copper than in 200 g of water.
[✓ B.] There are fewer degrees of freedom in 200 g of copper than in 200 g of water.
C. There are about the same number of degrees of freedom in 200 g of copper as there are in 200 g of water.
D. The information given doesn't tell you anything about the number of degrees of freedom in the matter.

1.2 (2 pts) From this you can conclude the following about the kinetic energy associated with moving in the x-direction (after the system has come to thermal equilibrium):

A. The average x-direction contribution to kinetic energy of a water molecule is greater than that of a copper atom.
B. The average x-direction contribution to kinetic energy of a water molecule is less than that of a copper atom.
[✓ C. The x-direction contribution kinetic energy of a water molecule is the same as that of a copper atom.]
D. The information given doesn't tell you anything about the x-direction kinetic energy of the molecules/atoms, only the overall kinetic energy.

2. (3 pts) A number N of H_2 molecules and N/2 O_2 molecules react to make H_2O, and all three are in the (ideal) gas phase. Which of the following is true?

➡ A. There are now N-H_2O molecules

➡ B. If the reaction takes place at constant temperature and pressure the final volume will be smaller than the initial volume

➡ C. If the reaction takes place at constant temperature and volume the final pressure will be lower than the initial pressure

D. If the reaction takes place at constant volume in an insulating box temperature must go down.

Equation of State of an Ideal gas $PV = \overset{\text{\# of molecules}}{\overset{\swarrow}{N}}\, kT$

Initial # of Molecules N + N/2 Final # of molecules N

3. (3 pts) The internal energy of an object at atmospheric pressure is observed to increase. At the same time its volume changes, but pressure is held constant. Which of the following is/are true?

A. Heat must have been added to the system.

➡ B. If the volume increased the system did positive work on its surroundings.

C. Since pressure is constant, enthalpy is conserved.

➡ D. If the volume increased heat must have been added to the system.

➡ E. If the enthalpy is constant, the volume must have decreased.

$\Delta U = Q - W$ $\qquad$ $W = P\Delta V$

$H = U + PV$ $\qquad$ at constant P, $\Delta H = Q$

Foothold ideas:
Entropy

- Entropy – an <u>extensive</u> measure of how energy is spread in a system.
- Entropy measures
  - The number of <u>microstates</u> in a given <u>macrostate</u>

    $$S = k_B \ln(W)$$

  - The amount that the energy of a system is spread among the various degrees of freedom
- Change in entropy

upon heat flow

$$\Delta S = \frac{Q}{T}$$

Let's build a simple model of sharing energy

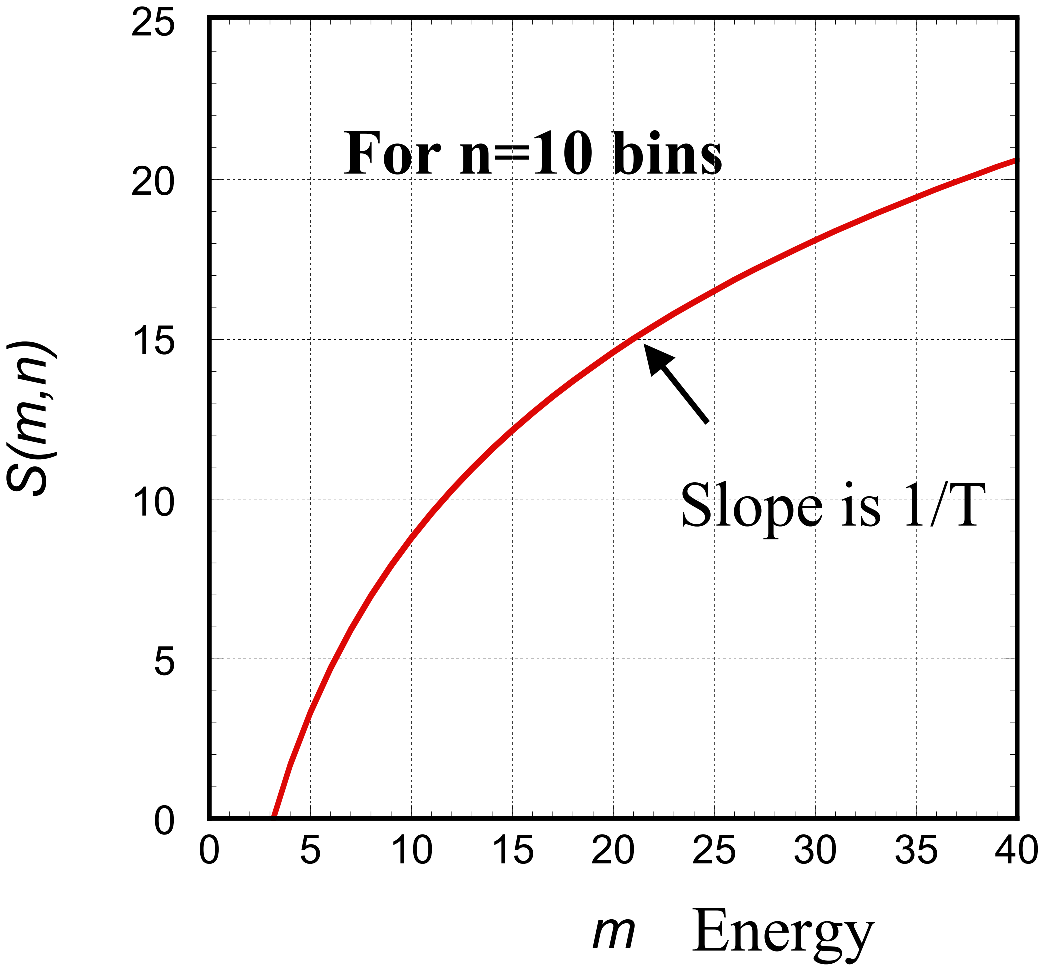
- Total amount of energy is conserved, Energy is divided into small *chunks*, shared among *bins.*
- Each *bin* can have an arbitrary number of *chunks* (but the total number of chunks for all bins is fixed).
- We are going to count, in how many ways this slicing of energy into *chunks* can be done.
- Each way of slicing is assumed to be equally likely.

Result

- What is entropy? S = ln (N)
- Why does entropy increase ? Max S most likely
- What is temperature? 1/T = dS/dU
- Why do two bodies in thermal equilibrium have the same temperature? Condition for maximum total S
- Where does the Boltzmann distribution come from? 1 Bin sharing with many Bins leads to exp[-U/kT]

Ta Da!

$$S(m,n) = \ln N(m,n) \qquad \frac{1}{kT} = \frac{dS(U)}{dU}$$



Remember:

m **represents total internal energy**

n **represents number of bins**

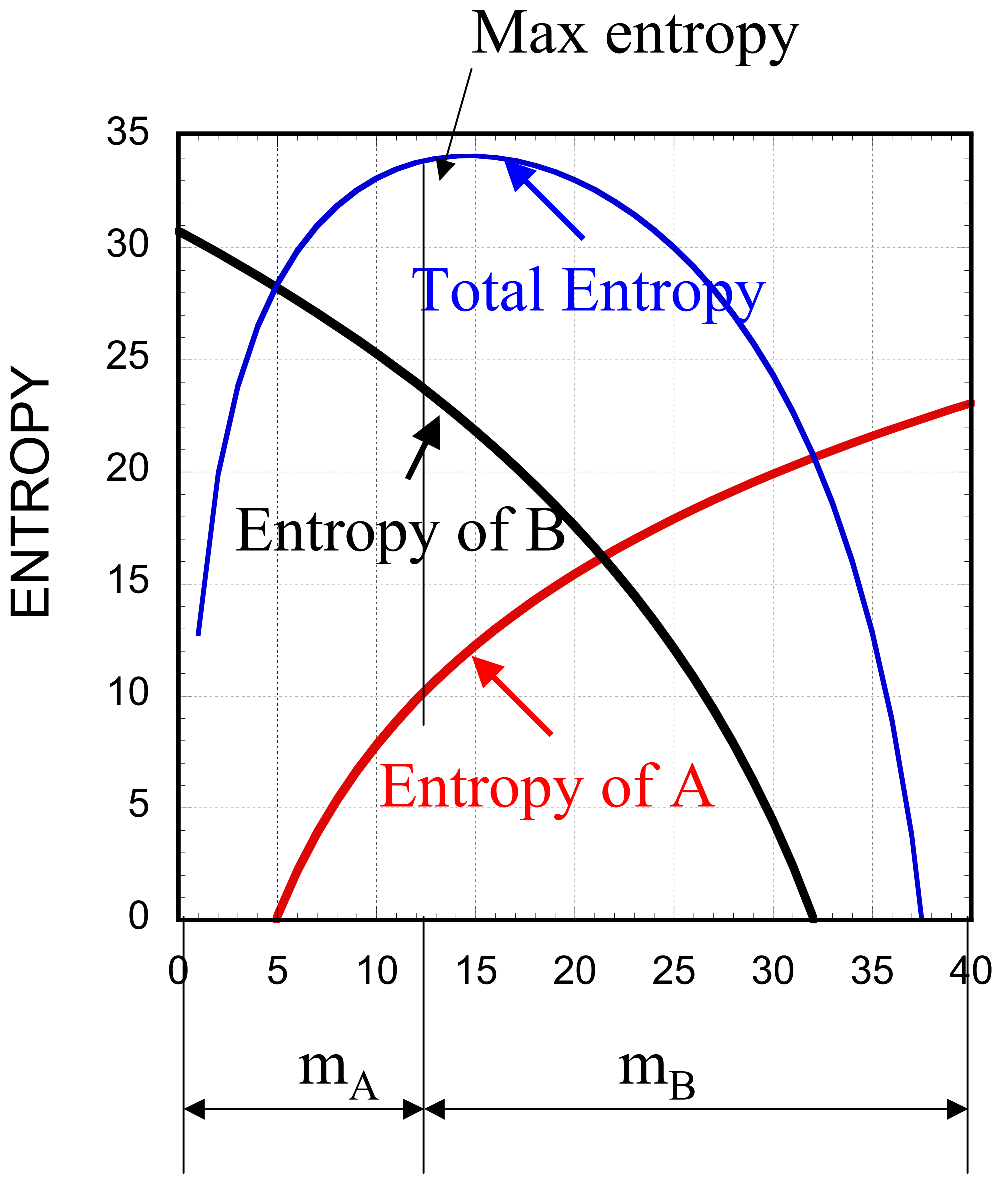
N represents number of arrangements.

Two systems share 40 chunks of energy

System A
12 bins

System B
20 bins

Who will wind up with more chunks of energy?



Equations of State (EOS) Macro-state variables

A. N- number of atoms
B. T - Temperature
C. P - Pressure
D. V - Volume
E. U - Internal Energy

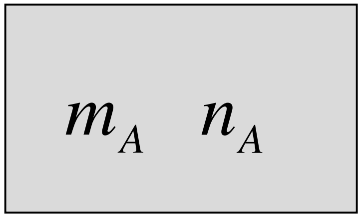
You specify 3

EOS tells the other 2

The Micro-state: how the internal energy is divided up among the many bins in the system

Micro-state versus Macro-state

System A



System A has n_A bins in which to store m_A chunks of energy.

This is referred to as the **macro-state**.
-n_A describes the system - how complicated is it?

- m_A tells how much internal energy it has.

The m_A chunks can be stored $N(m_A, n_A)$ ways.

Each of these is called a **micro-state**.

Foothold ideas: Entropy

- Entropy – an extensive measure of how well energy is spread in a system.
- Entropy measures
  - The number of microstates in a given macrostate
  - The amount that the energy of a system is spread among the various degrees of freedom
- Change in entropy upon heat flow

$$S = k_B \ln(W)$$

$$\Delta S = \frac{Q}{T}$$

Extensive versus Intensive

Extensive, proportional to the amount of material

E	A. N- number of atoms
I	B. T - Temperature
I	C. P - Pressure
E	D. V - Volume
E	E. U - Internal Energy
E	F. S - Entropy

which are intensive, which are extensive?

Whiteboard,
TA & LA

Foothold ideas:
The Second Law of Thermodynamics

- Systems spontaneously move toward the thermodynamic (macro)state that correspond to the largest possible number of particle arrangements (microstates).
  - The 2nd law is probabilistic. Systems show fluctuations – violations that get proportionately smaller as N gets large.
- Systems that are not in thermodynamic equilibrium will spontaneously transform so as to increase the entropy.
  - The entropy of any particular system can decrease as long as the entropy of the rest of the universe increases more.
- The universe tends towards a state of increasing entropy

Entropy of an Ideal Monatomic Gas

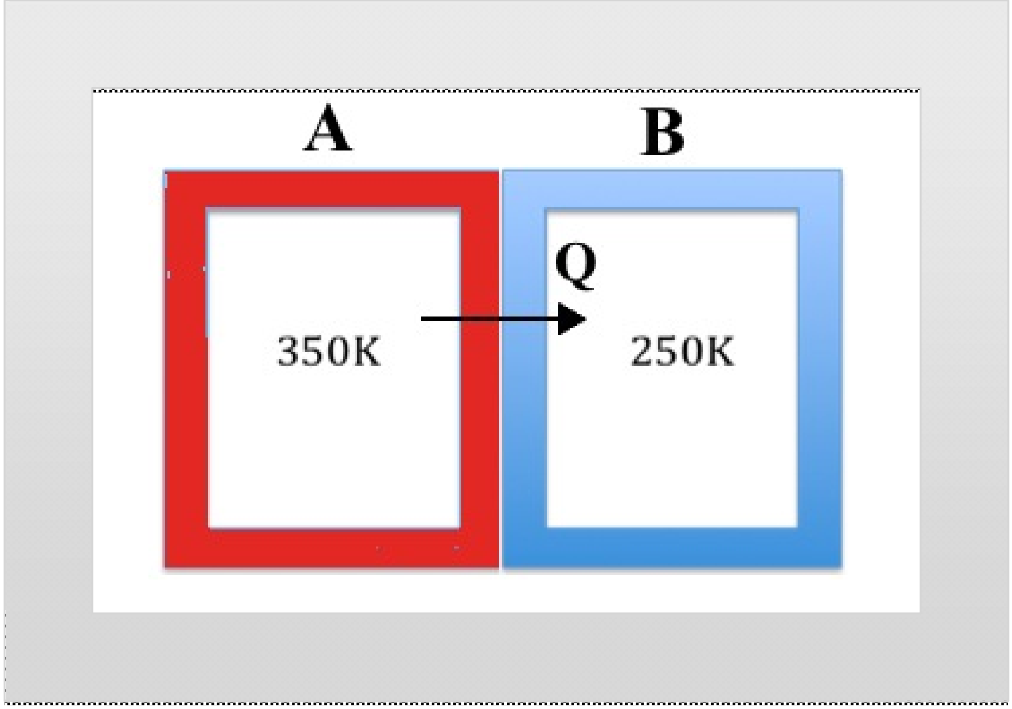
extrinsic

$$S = k_B N \left[\ln\left(\frac{V}{N} \left(\frac{U}{N}\right)^{3/2} \right) + const \right]$$

intrinsic

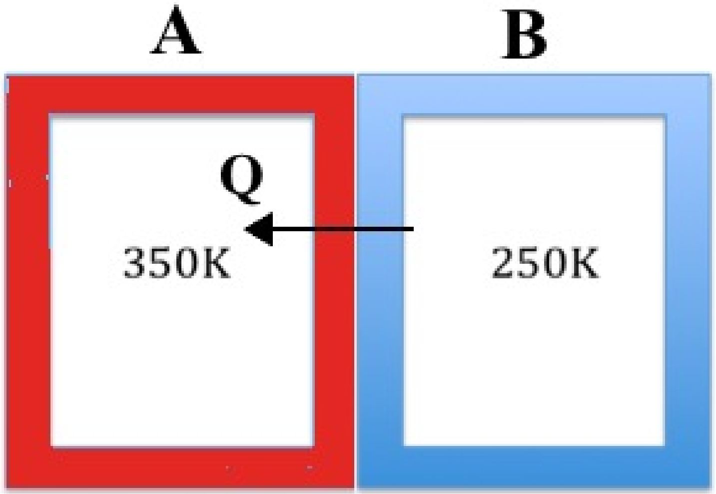
A small amount of heat Q flows out of a hot system A (350K) into a cold system B (250K). Which of the following correctly describes the entropy changes that result? (The systems are thermally isolated from the rest of the universe.)

1. $|\Delta S_A| > |\Delta S_B|$
2. $|\Delta S_B| > |\Delta S_A|$
3. $|\Delta S_A| = |\Delta S_B|$
4. It cannot be determined from the information given



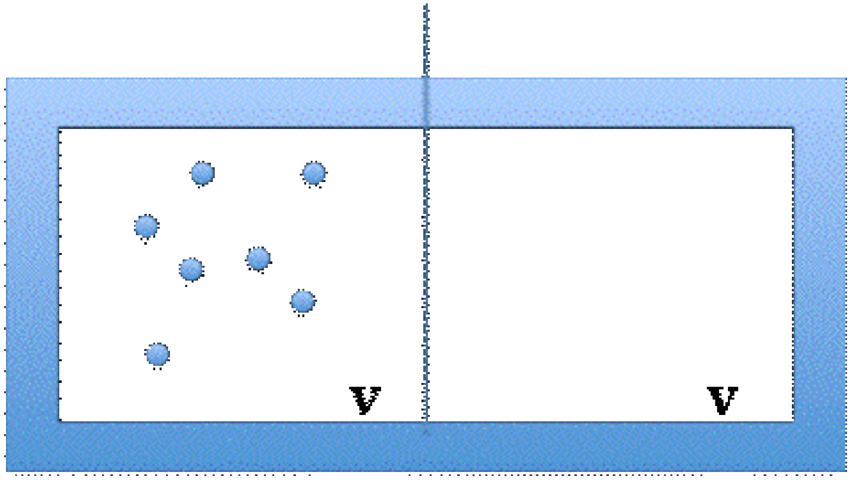
Suppose a small amount of heat Q is made to from a system A at low temperature (250K) to a system B at high temperature (350K). Which of the following must be true regarding the entropy of the rest of the universe during this process?

1. It increases by an amount greater than ($|\Delta S_A| - |\Delta S_B|$)
2. It increases by an amount less than ($|\Delta S_A| - |\Delta S_B|$)
3. It decreases
4. It stays the same
5. It cannot be determined from the information given



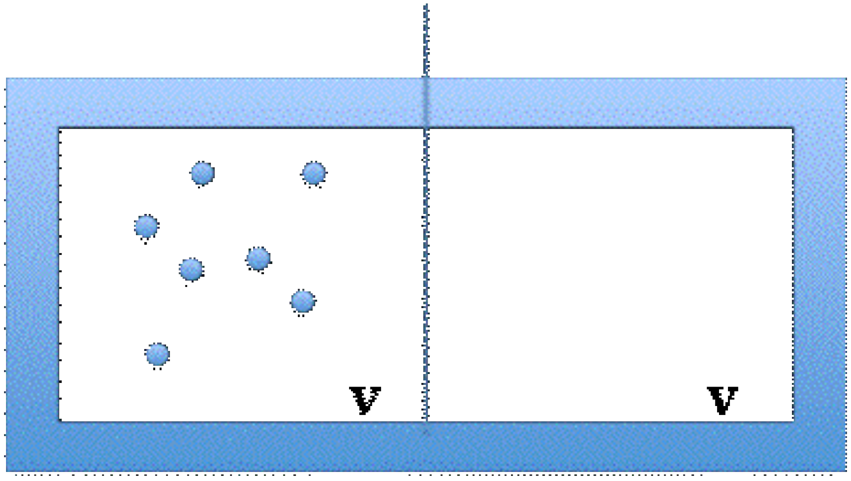
Suppose an isolated box of volume 2V is divided into two equal compartments. An ideal gas occupies half of the container and the other half is empty.
When the partition separating the two halves of the box is removed and the system reaches equilibrium again, how does the new **internal energy** of the gas compare to the internal energy of the original system?

1. The energy increases
2. The energy decreases
3. The energy stays the same
4. There is not enough information to determine the answer



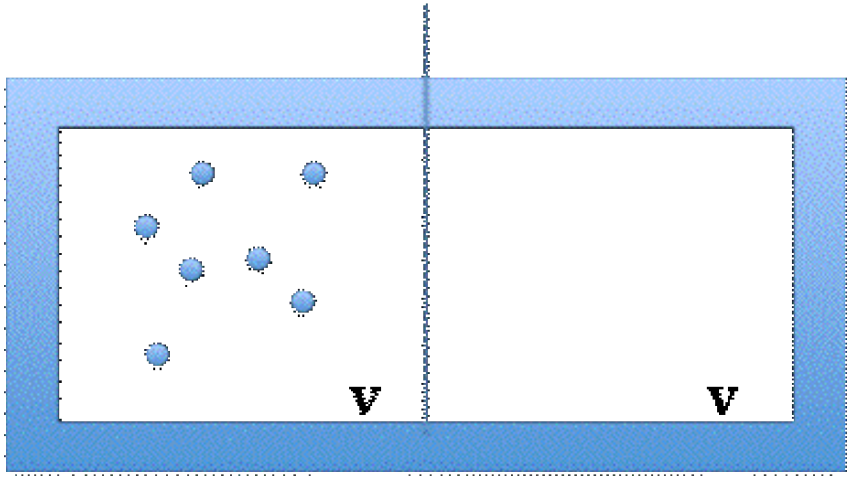
Suppose an isolated box of volume 2V is divided into two equal compartments. An ideal gas occupies half of the container and the other half is empty.
When the partition separating the two halves of the box is removed and the system reaches equilibrium again, how does the new **pressure** of the gas compare to the **pressure** of the original system?

1. The pressure increases
2. The pressure decreases
3. The pressure stays the same
4. There is not enough information to determine the answer



Suppose an isolated box of volume 2V is divided into two equal compartments. An ideal gas occupies half of the container and the other half is empty.
When the partition separating the two halves of the box is removed and the system reaches equilibrium again, how does the new **entropy** of the gas compare to the entropy of the original system?

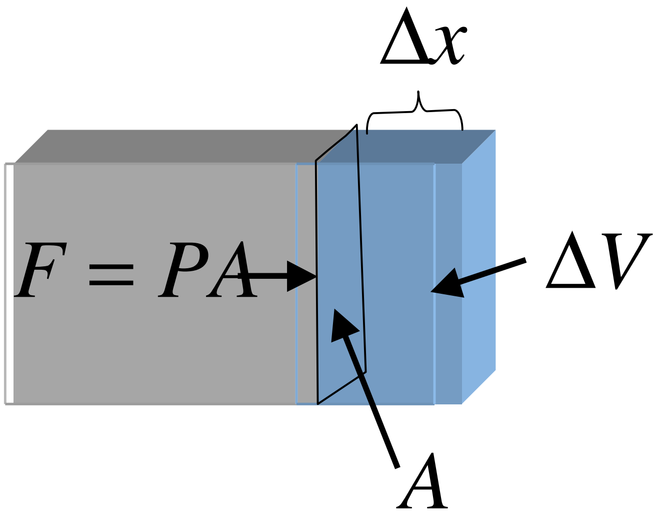
1. The entropy increases
2. The entropy decreases
3. The entropy stays the same
4. There is not enough information to determine the answer



Does the volume affect entropy?

1. In an ideal gas, atoms take up no volume so atoms have infinitely many microstates they may choose
2. Each atom has a finite volume, so the number of microstates increases with the available volume

What if the gas expands slowly against a piston?



Work done by the system on the outside world

$$W = \int_{V_1}^{V_2} P\,dV \sim P\Delta V$$

Internal energy goes	A. up	B. down	C. no change
Temperature goes	A. up	B. down	C. no change
Pressure goes	A. up	B. down	C. no change
Entropy goes	A. up	B. down	C. no change

Whiteboard,
TA & LA

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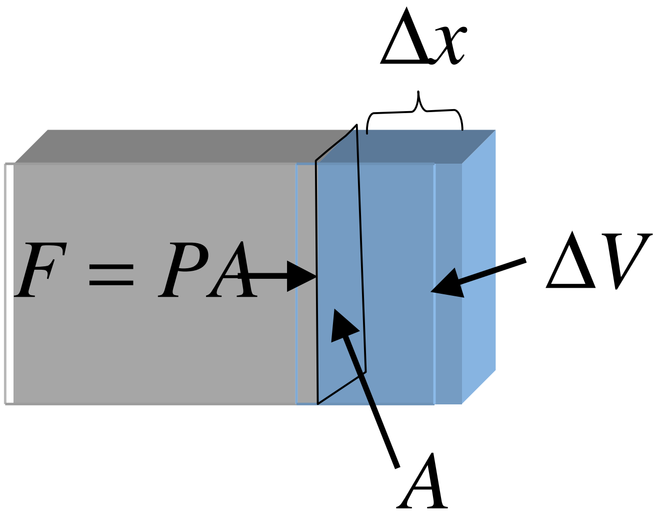

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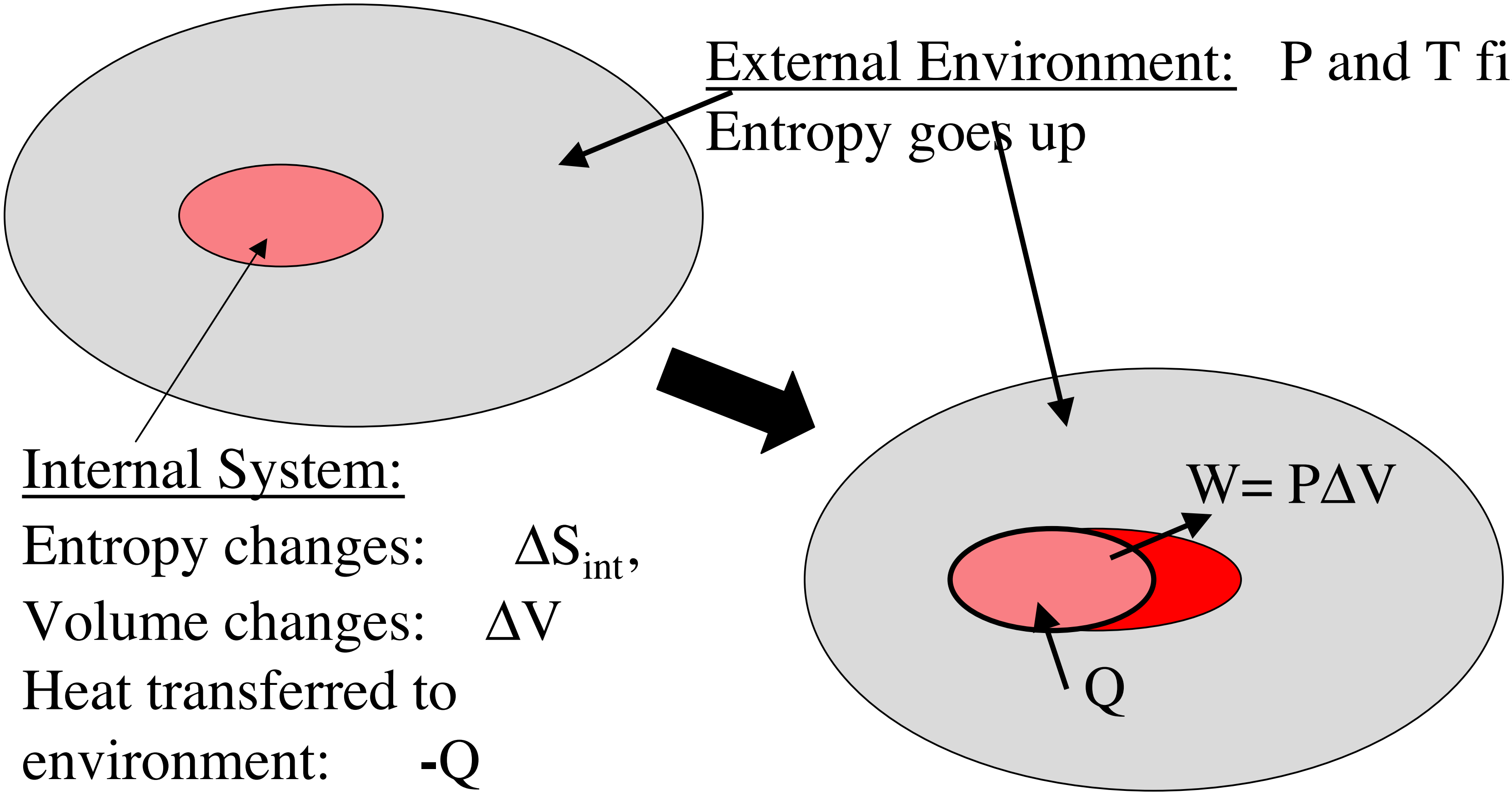
Entropy goes	A. up	B. down	C. no change

This is a reversible process, if motion of piston is reversed and returns to original position allvariables return to original values.

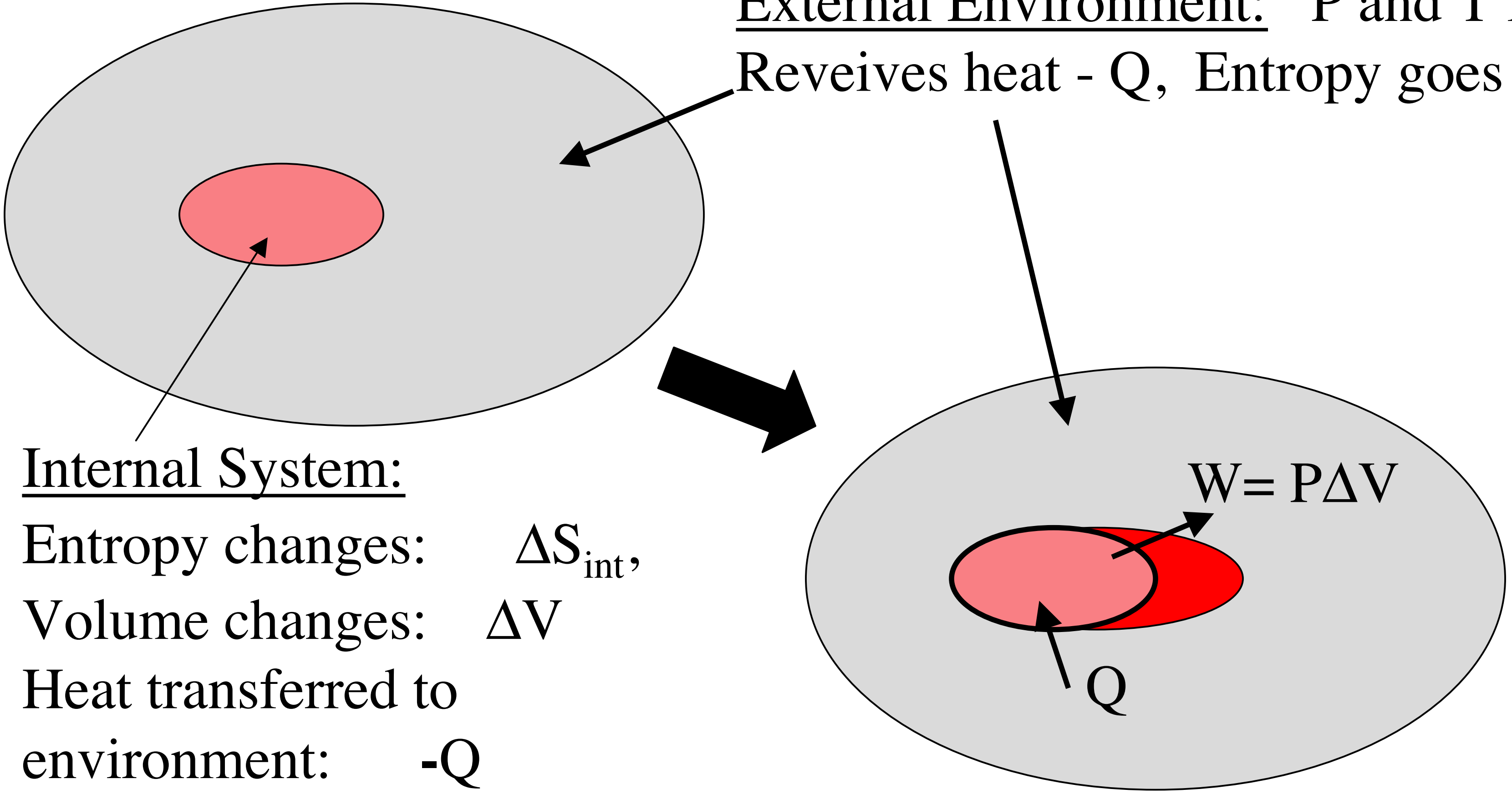
Gibbs Energy: Can a change happen?



External Environment: P and T fixed.
Entropy goes up

Internal System:
Entropy changes: ΔS_{int},
Volume changes: ΔV
Heat transferred to
environment: -Q

Change can happen if $T(\Delta S_{int} + \Delta S_{ext}) \geq 0$
But, $T\,\Delta S_{ext} = -Q = -\Delta H$



External Environment: P and T fixed.
Reveives heat - Q, Entropy goes up

Internal System:
Entropy changes: ΔS_{int},
Volume changes: ΔV
Heat transferred to
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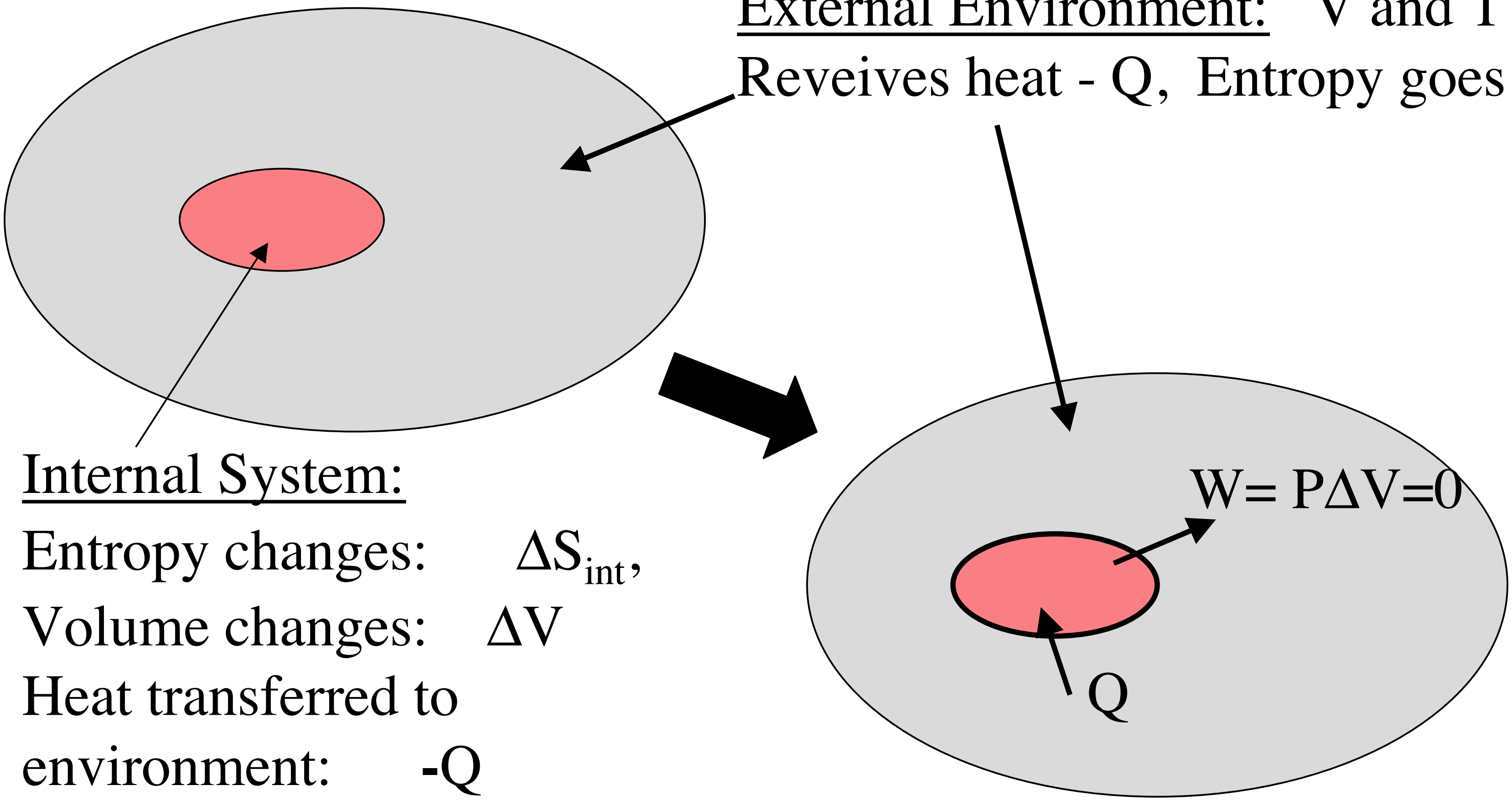
Change can happen if $T(\Delta S_{int} + \Delta S_{ext}) \geq 0$
But, $T\,\Delta S_{ext} = -Q = -\Delta H$

$T\Delta S_{int} - \Delta H \geq 0$ or $\Delta G = \Delta(H-TS) \leq 0$



External Environment: V and T fixed.
Reveives heat - Q, Entropy goes up

Internal System:
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Volume changes: ΔV
Heat transferred to environment: -Q

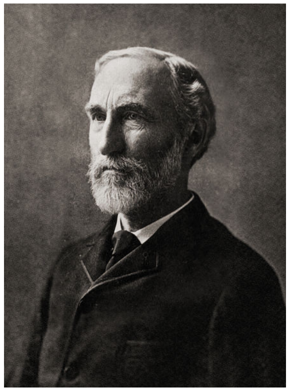
Change can happen if $T(\Delta S_{int} + \Delta S_{ext}) \geq 0$
But, $T\,\Delta S_{ext} = -Q = -\Delta U$

What if Volume is fixed?

Whiteboard, TA & LA

Josiah Willard Gibbs: 1839 -1903

http://en.wikipedia.org/wiki/Josiah_Willard_Gibbs



Tidbits from Wikipedia:

"In 1863, Yale awarded Gibbs the first American doctorate in engineering."

"... for a thesis entitled "On the Form of the Teeth of Wheels in Spur Gearing", in which he used geometrical techniques to investigate the optimum design for gears."

" ... was praised by Albert Einstein as "the greatest mind in American history"."

“ Gibbs, who had independent means and had yet to publish anything, was assigned to teach graduate students exclusively and was hired without salary.”

He was an intern before it was popular!

Known for

Statistical mechanics
Statistical ensemble
Gibbs entropy
Phase space
Gibbs free energy
Phase rule
Gibbs paradox
Vector calculus
Cross product
Gibbs phenomenon
Gibbs–Helmholtz equation
Gibbs–Duhem equation
Gibbs algorithm
Gibbs measure
Gibbs state
Gibbs–Thomson effect
Gibbs isotherm
Gibbs–Donnan effect
Gibbs–Marangoni effect
Gibbs lemma
Gibbs' inequality