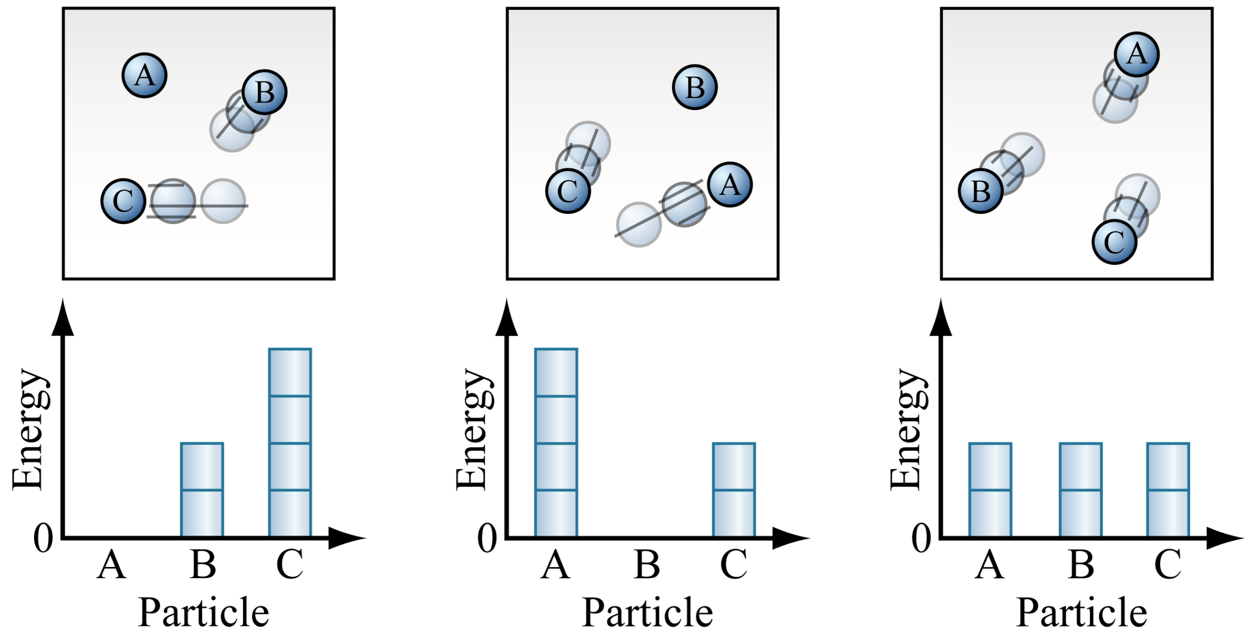
Statistical mechanics and entropy (for AP Physics 2)

Microstate – a particular configuration of the microscopic components of a system. When answering AP Physics 2 questions, try writing responses based on the (oversimplified) idea that each **distinct, particular apportionment of energy** among the microscopic components (e.g. atoms, molecules) of a system constitutes a microstate. It might not be necessary to worry in writing about distinguishing microstates by distinguishing particular positional placements and particular apportionments of momentum.



Fundamental postulate of statistical mechanics – Given enough time, all accessible microstates of a system are equally explored.

Entropy – a quantity that increases with the number of microstates explored by a system under specified conditions

$$S := k_{\mathrm{B}} \ln(\text{Number of microstates})$$

The change in a system's entropy during a process connecting an initial system state to a final system state is proportional to the heat that would be delivered to the system during a reversible process that would connect the same initial and final system states.

$$\Delta S_{\mathrm{SYS}} = \frac{\Delta Q_{\mathrm{REV,INTO\ SYS}}}{T}$$

gaining heat

↔

gaining energy that can be apportioned among system components in various ways

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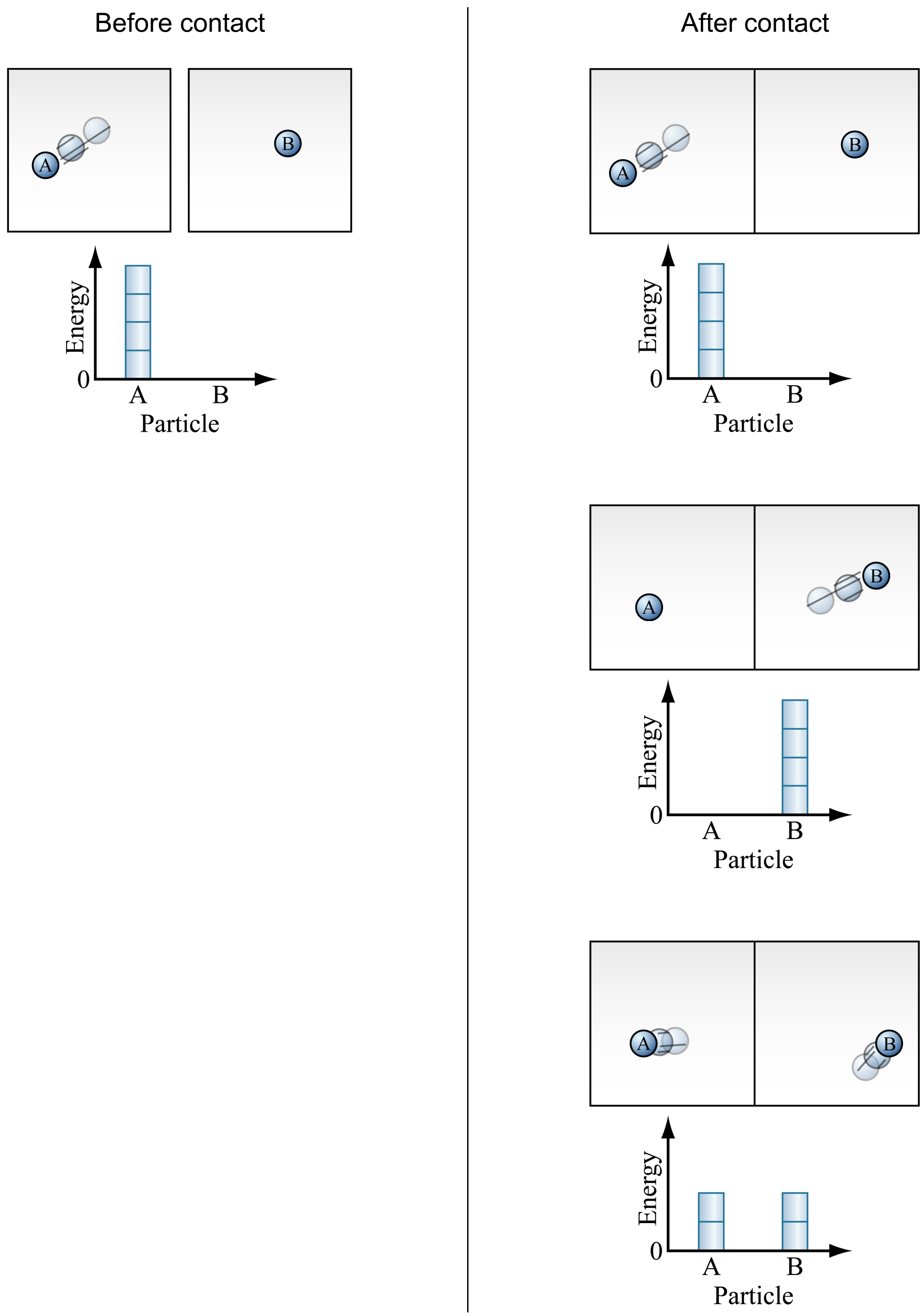
Second law of thermodynamics

The entropy of an *isolated* system (exchanges neither particles nor energy with surroundings) is non-decreasing. Specifically, for a spontaneous process, the entropy increases.

$$\Delta S_{\text{ISOLATED}} \geq 0$$



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Heat flows from higher temperature to lower temperature. If two objects are in thermal equilibrium, they are at the same temperature, and no net flow of heat occurs between them.

Example problem: Separate containers A and B contain identical numbers of molecules of an ideal gas. Initially, the temperature of the gas in container A is greater than the temperature of the gas in container B. The containers are brought into contact and heat can transfer between them. The two containers are allowed to reach thermal equilibrium. The containers remain otherwise separated from the outside world.

a) For each container, specify whether energy is gained, lost, or unchanged. Provide reasons.

Container A initially has a higher temperature, so heat flows from container A to container B. Container A loses energy while container B gains an equal amount of energy.

b) For each container, specify whether entropy increases, decreases, or remains unchanged as a result of bringing the containers into contact. Provide reasons.

After losing some energy, container A now contains fewer units of energy. Because it has fewer units of energy, the number of specific ways to apportion container A's energy among its gas molecules has decreased. The entropy of a system increases as the number of microstates explored by a system increases. Thus, container A has decreased entropy.

On the other hand, because container B gains energy, there are more ways to apportion the energy in container B among its gas molecules. The number of microstates associated with container B has increased, and, thus, so has its entropy.

c) For the system overall, specify whether entropy increases, decreases, or remains unchanged. Provide reasons.

The second law of thermodynamics states that the entropy of an isolated system increases during a spontaneous process. Once they are brought into contact and left in contact, containers A and B together constitute an isolated system. Thus, the spontaneous transfer of heat from container A to container B corresponds to an increase in entropy. Another way to see that the entropy of the combined system consisting of containers A and B increases is to recognize that the combined energy of the two containers was initially concentrated in container A but is now able to be more evenly distributed among the gas molecules of both containers. Thus, the number of microstates explored by the gas molecules of the combined system as those gas molecules bounce around and exchange energy in an ongoing way is increased. Thus, the entropy has increased.