

University of Maryland
Department of Physics

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Physics 132
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Exam 1 (Sample Problems)

(25 points) 1.1 (5 pts) If you flip a fair coin 12 times, which string of heads and tails are you more likely to get?

- I: HHHHHHHHHHHH
II: HTHTTHTHTTTH

- A. String I
B. String II
C. They are equally probable
D. You can't tell without being given more information.

1.2 (5 pts) If you flip a fair coin 12 times, which result are you more likely to get?

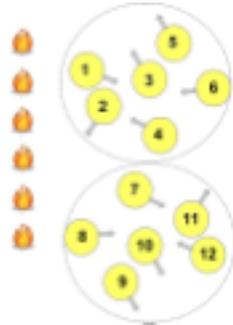
- i: 12 heads
ii: 6 heads and 6 tails

- A. Result i
B. Result ii
C. They are equally probable
D. You can't tell without being given more information.

1.3 (5 pts) You have 12 molecules in different locations in a two part box as shown in the figure and they are numbered as shown. If you add 6 packets of energy to the molecules at random, which result are you more likely to get?

- I. Molecules 1, 2, 3, 4, 5, 6 get energy
II. Molecules 2, 5, 6, 9, 10, 12 get energy

- A. Set I
B. Set II
C. They are equally probable
D. You can't tell without being given more information.



1.4 (5 pts) You have 12 molecules in different locations in a two part box as shown in the figure and they are numbered as shown. If you add

6 packets of energy to the molecules at random, which result are you more likely to get?

- i: 6 packets in the top box
ii: 3 packets in the top box and 3 packets in the bottom box

- A. Result i
B. Result ii
C. They are equally probable
D. You can't tell without being given more information.

1.1 C

1.2 B

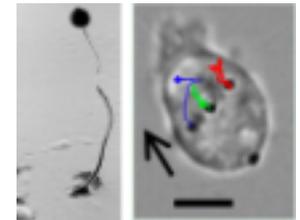
1.3 C

1.4 B

In problems 1.1 and 1.3 each individual arrangement (microstate) is equally probable. Since the microstates are equally probable, the macrostate that corresponds to more microstates (possible arrangements that give the same macro result) is more probable.

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(15 points) Slime mold cells feast on bacteria and yeast and essentially any food that comes their way. However, if they are out of food, they signal to each other and move together with about 100,000 of their best friends to form a spore. A typical spore is shown on the right. Unfortunately the image does not have a scale bar so we are not sure how large it is. Someone (Juan Lasheras, UCSD) did, however, take a picture of a single cell as shown on the right, with a scale bar of 5 microns. Estimate how heavy a spore is (in Newtons). (Note that the spores are just large enough to survive as a group yet light enough and high enough above the surface to be carried away by the wind!) Be sure to clearly state your assumptions and how you came to the numbers you



estimated, since grading on this problem will be mostly based on your reasoning, not on your answer.

We know how many cells are in a spore (10^5) and we know the approximate size of a single cell (diameter ~ 10 microns). So all we have to do is estimate the mass of one cell, scale it up by 10^5 to get the mass of the spore, and multiply by g ($\sim 10 \text{ N/kg}$) to get its weight. Let's model the cell by a cube (good enough for an estimate) and assume it has about the same density as water – 1 gram/cm^3 – but I want to do it in kg and m so the density of water is 1000 kg/m^3 (about 1 ton per cubic meter). Taking the size of the cube as being about 10 microns on a side

$$\text{Volume of single cell} \sim (10^{-5} \text{ m})^3 = 10^{-15} \text{ m}^3$$

$$\text{Mass of single cell} \sim (10^3 \text{ kg/m}^3) \times (10^{-15}) \text{ m}^3 \sim 10^{-12} \text{ kg}$$

$$\text{Mass of spore} = 10^5 \times \text{mass of single cell} \sim 10^{5-12} \text{ kg} = 10^{-7} \text{ kg}.$$

$$\text{Weight of spore} = mg = (10^{-7} \text{ kg})(9.8 \text{ N/kg}) \sim 10^{-6} \text{ N}$$

About a micro-Newton.

[Grading: Stating assumptions +4; estimating volume of single cell +2; density of water +2; mass of single cell +3; mass of spore +2; weight +2]

(10 points) Three 132 students are discussing energy. Melanie says, “We don't need to talk about chemical energy at all. It's just the kinetic and potential energies of electrons and nuclei.” Steve says, “We don't need to talk about thermal energy at all. It's just the kinetic and potential energy of atoms and molecules.” Mike says, “But in biology, we sometimes talk about both chemical and thermal energy. I think it's useful.” Who do you agree with and why? Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.

There is not a unique answer to this. Your answer will be evaluated on the clarity of your statements and it's reasoning. One possible answer is the following.

While it is true that all energies are kinetic or potential energies of something, we don't always want to pay attention to every particle in a system we are considering down to the electrons and the nuclei. If we are talking about a macroscopic object, it might be convenient to “black box” the motion of the atoms and molecules of which the object is made and treat energy that is transformed from the coherent energy of the

entire object down into the incoherent energy of the atoms and molecules of the object. Macroscopically we can see coherent kinetic energy (it goes with momentum) but the incoherent energy has to be inferred (after measuring temperatures). It might be convenient to lump it as “thermal” and not consider what it's made up of.

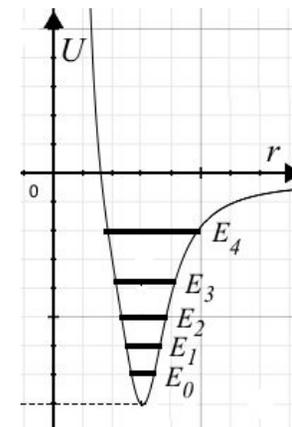
Even if we are considering the motion of atoms and molecules, we might not want to consider the motion of the electrons and nuclei inside the atoms and molecules. As such, when a chemical reaction occurs, we might not want to specify it a change in the kinetic and potential energies of electrons, but just treat it in a lump as “chemical energy”.

So the utility of these characterizations of energy depends on what it is we want to focus on and what we are trying to do.

[Grading: Statement of position +2; quality of argument for thermal +3; quality of argument for chemical +3; resolution +2.]

(25 points)

A. A molecule that is a bound state of two atoms, A and B, has the potential energy between its atoms shown in the figure at the right. When it is in water at STP, it is typically in its ground state, E_0 . When it is in this state, it does not react with an atom C that is also found in the water. But when it is in its excited state, E_1 , the reaction $AB + C \rightarrow A + BC$ can take place. If $\Delta E = E_1 - E_0 = 500 \text{ meV}$ (milli-electron Volts), what is the probability that the AB molecule will be found in state E_1 ? Put your answer in the box and show your reasoning in the space below. (7 pts)



The probability that a degree of freedom interacting with a random motion thermal bath gains an energy ΔE is given by the Boltzmann factor

$$P(\Delta E) \propto e^{-\Delta E/k_B T}$$

where $k_B T$ is about 1/40 eV at STP. This is

$$1/40 \text{ eV} = 0.025 \text{ eV} = 250 \text{ meV}$$

so the probability will be given by the Boltzmann factor of ΔE compared to the BF of 0 so

$$\frac{\Delta E}{k_B T} = \frac{500 \text{ meV}}{25 \text{ meV}} = 20$$

and our probability will be

$$e^{-20} \sim 2 \times 10^{-9}.$$

[Grading: Boltzmann Factor +3, correct values put in +2; value +2.]

B. Consider the reaction $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$. The following bond energies have been determined experimentally:

- H-H 436 kJ/mol
- O=O 497 kJ/mol
- H-O 464 kJ/mol

B.1 In this reaction, what is the difference in chemical energy between the reactants and the products? (8 pts)

In the initial state there are 2 H-H bonds and 1 O=O bond for a total of

$$2 \times 436 \text{ kJ/mol} + 497 \text{ kJ/mol} = 1369 \text{ kJ/mol}$$

In the final state there are 4 HO bonds (the two H do not bond to each other in a water molecule) so the final bond energy total is

$$4 \times 464 \text{ kJ/mol} = 1856 \text{ kJ/mol}.$$

The result is that there is more bond energy in the final state by

$$1856 \text{ kJ/mol} - 1369 \text{ kJ/mol} = 487 \text{ kJ/mol}.$$

[Grading: initial state +3; final state +3; difference +2; -1 for no units.]

B.2 Does your answer to part B.1 represent a net input of energy, or a net release (output) of energy if the reaction proceeds in the direction indicated? How do you know? (5 pts)

If the reaction goes in the direction indicated it represents a RELEASE of energy since the final system is more tightly bound (the PE is more

negative). This can be confusing because the bond energy is the negative of the potential energy.

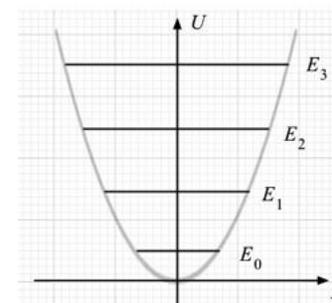
[Grading: answer +3; reason +2]

B.3 Assume this reaction takes place inside a thermally insulated container with hard walls. Since the energy of the universe has to be conserved (and in this case, energy can't enter or leave the system), where did the energy [input | output] you found in part B.2 [come from | go]? Be as specific as possible. (5 pts)

The energy will be found in an increased kinetic energy of the product molecules compared to the KE of the initial state molecules. Chemical energy is converted to thermal energy.

[Grading: answer +3; reason +2]

(10 pts) Real molecules have to be treated by quantum, not classical, mechanics. Although the classical treatment gives a correct description of the parameters involved and of the potential energy, there are differences. In the classical treatment, any energy is allowed; in the quantum treatment, only particular energy levels are allowed, as shown in the figure at the right.



The lowest level permitted (the ground state, E_0) is not at the bottom of the well but a little up from it. For a simple harmonic oscillator, the spacing between neighboring allowed levels is $\Delta E = hf$. According to our study of thermodynamics, we know that the relative probability of a molecule being excited by an amount $\Delta E = E - E_0$ in a medium at temperature, T , has the form

$$\frac{P(E)}{P(E_0)} = e^{-\Delta E/\epsilon}$$

where ϵ is a parameter that has units of energy and depends on T .

2.1 (5 pts) If we are using ΔE to represent the excitation energy of a single diatomic molecule, and the molecule is in a human body at normal body temperature of 37 °C, what value should we take for ϵ ?

- A. 3.1 meV
- B. 25 meV
- C. 26 meV
- D. 0.03 kJ
- E. 2.4 kJ
- F. 2.5 kJ
- G. Something else (give it on your answer sheet).

2.2 (5 pts) If the value of hf for our diatomic molecule is ~ 0.22 eV, and the energy of the ground state is 0.11 eV, what is the probability of finding it in a living human body in its first excited state?

- A. ~ 1
- B. $\sim 1 \times 10^{-2}$
- C. $\sim 2 \times 10^{-4}$
- D. $\sim 8 \times 10^{-4}$
- E. Something else (give it on your answer sheet).