CONCEPTESTS FOR A THERMODYNAMICS COURSE

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McDermott[1] found that few students developed a functional understanding of the material in an introductory physics course. Instead, students entered the class with misconceptions, and these misconceptions were not displaced by lectures. McDermott stated that students must be allowed to apply their own ideas, so that when they fail, students are more likely to learn the correct concepts. She found that "an effective instructional approach is to challenge students with qualitative questions that cannot be answered through memorization." This is because students in science and engineering courses often solve quantitative problems by memorizing an algorithm; as a result they do not obtain a functional understanding, which means they cannot use their knowledge in new situations.[1]

A recent paper[2] discussed the use of conceptests in a chemical engineering thermodynamics class. These conceptests show that many students don't understand basic concepts that they used in previous courses, such as vapor pressure (Example 1) and the ideal gas law (Example 2). The use of conceptests and clickers will be described briefly, and then examples of conceptests for thermodynamics will be presented. These conceptests replace much of the lecture. Explaining the motivation for clickers at the beginning of the semester is important. Also, few quantitative problems are done in class, but the students do at least as well on quantitative problems on exams. The students answer multiple-choice, qualitative questions using small, hand-held clickers. Students then discuss their answers with fellow students. We used infrared clickers for the first three years,[3] and in 2006 we used RF clickers,[4] which cost the same but are much faster and do not require any classroom installation.

The motivation for using clickers[5] with conceptual questions[6, 7] is to increase students' conceptual understanding and to change their misconceptions. This approach provides

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instant feedback on student understanding from everyone in class, so that the instructor can use class time to concentrate on clearing up confusing concepts. It creates a more-engaged learning environment and it allows students to determine how well they understand key concepts. It also allows them to apply their own ideas and to learn from and teach their fellow students. Students thus hear explanations that may differ from those presented by the instructor; a student who recently learned the concept may often better understand what confuses a fellow student. Conceptests and clickers also make teaching more enjoyable for the instructor. Students like this mode of instruction: Class discussions are more lively, attendance is higher, and students are more motivated to be prepared.

CLASSROOM USE OF CLICKERS

An approach for using clickers and peer instruction[5, 6] is as follows:

1. *The instructor poses a multiple-choice conceptual question.*
2. *Students, working alone, enter an answer using their individual clickers, and the answers are collected by the instructor's computer. The clickers have unique ID numbers, which can be registered at the start of the semester.*
3. *After a few minutes, the instructor pauses the acquisition of answers, and uses the histogram of answers on his/her computer to determine the students' level of understanding. The students are not shown the histogram. A good question typically has less than 50% correct answers.*
4. *The instructor then asks students to discuss their answers with neighbors (peer instruction[6]), and asks them to either change their answers or convince their neighbors who disagree with them to do so. The instructor can walk around the classroom to answer questions and determine how students are doing.*
5. *After a few minutes, the instructor looks at the histogram of answers again. If most students have the correct answer, he/she either explains why it is correct or asks students to explain why.*
6. *If the students have not converged on the correct answer, the instructor can try to clarify the question or spend more time on the concept.*

We typically used two to four clicker questions in a 50-minute class. The student answers are graded to provide motivation, with three points for the correct answer and two points for a wrong answer. The five days with the lowest averages for each student were not counted in grading. The clicker grade counted 10% of the total course grade, and the class average has been close to 90%. This grading provided sufficient motivation for students to attend class and to be prepared. To encourage cooperation instead of competition, the course was not graded on a curve; a fixed grading scale was presented at the beginning of the semester.

Reading was assigned for each class to prepare students for in-class conceptests. A graded reading quiz, consisting of two to four questions, had to be completed online before class using WebCT software. Each homework assignment and each exam had conceptual questions similar to those in class, but they were not multiple choice, and the students had to provide explanations for their answers. Approximately 40% of each exam grade was from conceptual questions. The exam questions were different from those in class, but they tested the same concepts.

DEVELOPING CLICKER QUESTIONS

The type of clicker questions used can make a significant difference in students' learning and motivation. Some suggestions for effective clicker questions are:

- *Use conceptual questions, not numerical calculations.*
- *Identify the concepts that are most confusing.*
- *Develop good wrong answers that bring out student misconceptions. Previous exams are a good source of wrong answers.*
- *Aim for 50% or less correct answers; if 90% are correct initially, the question is probably not a good use of class time.*

As shown in the examples for chemical engineering thermodynamics, additional conceptests can be developed with small variations on a conceptest by:

- *Increasing instead of decreasing a variable*
- *Changing a different variable*
- *Using a flow system instead of a static system*
- *Using a liquid-to-solid instead of gas-to-liquid phase change*
- *Holding a different variable constant*
- *Using a different method to change the same variable*

Asking students to choose between several graphical representations is an effective conceptest, such as asking which process on a T-S diagram is correct (Example 8), or which curve is incorrect on a P-H diagram (Example 9), or how does the mole fraction change with pressure (Example 12). Using this approach, approximately 275 conceptests have been developed for a chemical engineering thermodynamics course, and PowerPoint versions of them can be obtained upon request.[8]

STUDENT FEEDBACK

Anonymous student feedback has been positive. Of the 53 students in the fall 2005 thermodynamics course, 38 *specifically* mentioned in an anonymous end-of-semester evaluation that they liked clickers and conceptests. One student did not like them and said that the lectures rely too heavily on clickers. One comment indicated that students have not always had good experience with clickers: "Clickers, surprisingly, were

EXAMPLES

The correct answers are underlined.

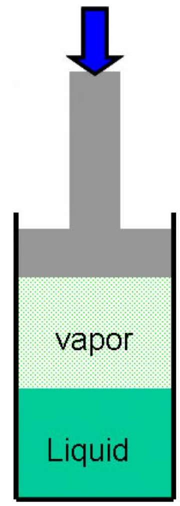
Vapor Pressure

Question 1. Liquid water is in equilibrium with air at 50 °C in a piston/cylinder system at 1 atm pressure. The total pressure is raised to 2 atm by pushing on the piston. Temperature is constant. At equilibrium, the *partial pressure* of the water:

A. Decreased

B. Increased

C. Remained the same



When this question was given as an online quiz at the beginning of the semester in 2005 (ungraded, but credit given for completing the quiz), only 14 students out of 51 selected the correct answer (C), and 22 selected A. Since chance would result in 17 correct answers, this question indicates students have significant misconceptions about vapor pressure. This question was also put on the final exam, but it was not multiple choice. Instead, students had to describe what happened and why. On the final exam, 35 students answered correctly with the correct explanation. This was more demanding than the online question at the start of the semester since they had to provide an explanation.

Variations on this question: Instead of a pressure increase to 2 atm, the students can be asked what happens if:

a) Total pressure decreased to 0.75 atm

b) Liquid water added to system at constant T, P

c) Water vapor added at constant T, P

d) Air added at constant T, P

e) Air removed at constant T, P

f) Water vapor and air removed at constant T, P

The same concept can be used in a flow system, where the total pressure is lowered. Instead of asking what happens to the partial pressure of water, the question can ask if the amount of water in the vapor phase (or liquid phase) increases or decreases.

Question 2. A piston/cylinder system at 45 °C contains 0.9 mol hexane vapor and 0.1 mol hexane liquid at equilibrium. The pressure was doubled at constant temperature. What is the final state of the system?

A. The system contains all vapor

B. The system contains all liquid

C. Some of the liquid had vaporized

D. Some of the liquid has condensed

When this question was given as an online quiz at the beginning of the semester in 2006, *only 5 students out of 69 correctly selected B*. More students (9) selected C; *i.e.*, they answered that liquid vaporized when the pressure increased. Note that all these students had done multiple problems dealing with vapor pressure in a prerequisite course.

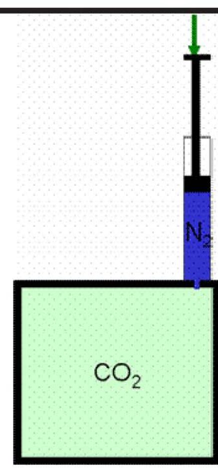
Ideal Gas

Question 3. A constant-volume tank contains CO_2 at 2 atm. Nitrogen is injected into the tank. What happens to the *partial pressure* of CO_2 if it all remains in the tank? Assume ideal gases.

A. Decreases

B. Increases

C. Stays the same



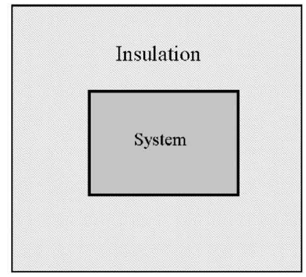
When this question was given as an online quiz at the beginning of the semester in 2005, only 6 students out of 51 correctly selected C. Most students (32) selected B, demonstrating how prevalent misconceptions are about a basic concept that was used extensively in several previous courses.

EXAMPLES, CONTINUED

First Law

Question 4. An explosion takes place in a closed tank that is completely insulated. What happens to the energy of the system (tank plus contents)?

A. Stays the same
B. Decreases
C. Increases
D. Insufficient information



When this question was given as an online quiz at the beginning of the semester in 2005, only 9 students out of 51 correctly selected A, whereas 37 selected B.

Variations on this question

a) Use endothermic reaction instead of exothermic.
b) Make it isothermal instead of adiabatic.

Heat of Reaction

Question 5. Which has the higher adiabatic temperature for an oxidation reaction? A feed that contains

A. a stoichiometric amount of pure O_2
B. 50% excess oxygen (pure)
C. a stoichiometric amount of air

Variations on this question:

a) Use an endothermic reaction and change the amount of inert in the feed.
b) Ask which has higher temperature if the flow rate to the reactor is cut in half.

Phase Change

Question 6. Solid water becomes a liquid when the pressure increases isothermally. The entropy of the water:

A. Increases
B. Decreases
C. Does not change

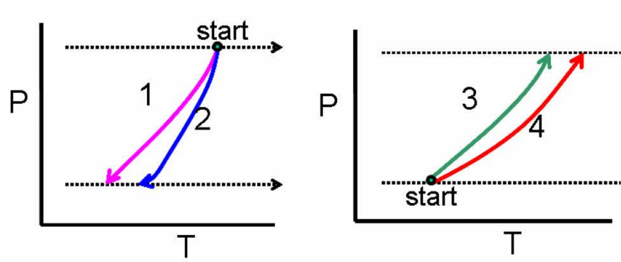
Variation on this question

Use ethanol so that liquid becomes solid as pressure increases.

Reversible Processes

Question 7. Adiabatic expansions and compressions are shown in the two graphs. One curve represents a reversible process and one an irreversible process in each figure. Which curves are for the irreversible processes?

A. 1 & 3 B. 1 & 4 C. 2 & 3 D. 2 & 4

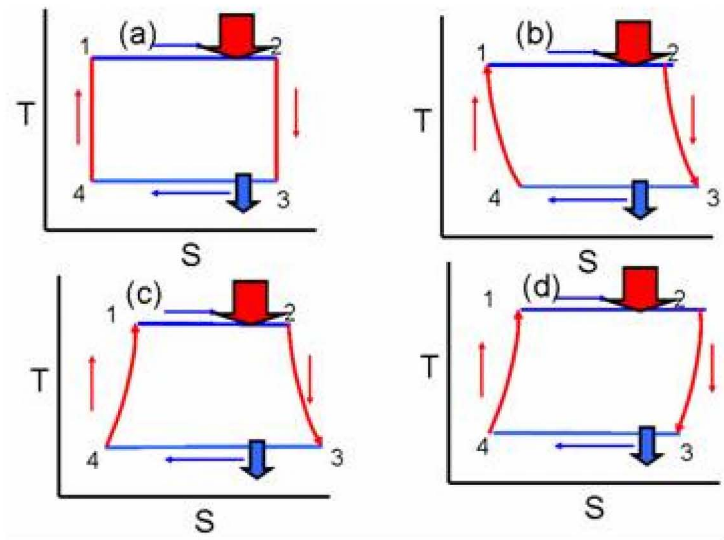


EXAMPLES, CONTINUED

Cycles

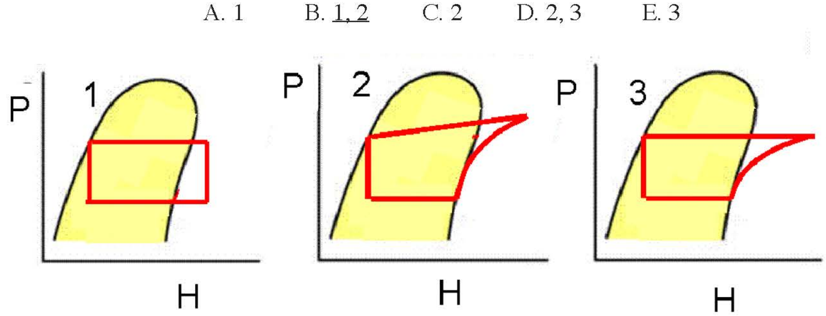
Question 8. Which diagram corresponds to a Carnot engine in which both adiabatic steps in the cycle are *irreversible*?

Correct answer: (c)



Question 9. Which diagrams are not possible for a vapor compression refrigeration cycle using a throttling valve?

A. 1 B. 1, 2 C. 2 D. 2, 3 E. 3



actually used effectively; they are almost always otherwise a complete waste of time." A few additional sample student comments were:

> *"The most conceptually challenging ChE course I have had and the class I have been the most consistently motivated for."*
>
> *"Really liked lectures, not rigid, but focused on what we had trouble understanding."*
>
> *"Most effective methods of teaching were concept tests."*
>
> *"Concept tests make me think thoroughly and completely about every subject."*
>
> *"I know a lot more now than I ever dreamed I would know. One of the biggest learning techniques was concept tests."*

REFERENCES

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2. Falconer, J.L., "Use of ConcepTests and Instant Feedback in Thermodynamics," *Chem. Eng. Ed.*, **38**, 64 (2004)
3. <www.h-itt.com>
4. <www.iclickers.com> Free software that acquires student responses and grades the results is provided by iclickers. The receiver connects to a USB port and contains a small LCD screen so that the instructor can see the student responses.
5. Duncan, D., *Clickers in the Classroom*, Addison Wesley (2005)
6. Mazur, E., *Peer Instruction*, Prentice Hall (1997)
7. Landis, C.R., A.B. Ellis, G.C. Lisensky, J.K. Lorenz, K. Meeker, and C.C. Wamser, *Chemistry ConcepTests: A Pathway to Interactive Classrooms*, Prentice Hall (2001)
8. Contact john.falconer@colorado.edu ❒

EXAMPLES, CONTINUED

Binary Vapor-Liquid Equilibrium

Question 10. Your technician reported that when he decreased the temperature for a binary gas-phase mixture of C_6 isomers, n-hexane condensed before 2,2 dimethylbutane (DMB). Can this happen?

A. Yes, if n-C_6 has a lower vapor pressure than DMB

B. Yes, if n-C_6 has a higher vapor pressure than DMB

C. <u>No, because both species have to condense</u>

D. It depends on the system pressure as to whether one or two species condense

When this question was given as an online quiz at the beginning of the semester in 2006, *only 1 student out of 69 correctly selected C*. Note that all students have solved multiple Raoult's Law problems in a prerequisite course.

Variations on this question

a) Increase pressure instead of lowering temperature.

b) Start with liquid and raise temperature and state that only one component evaporates.

c) Start with liquid and lower pressure and state that only one component evaporates.

Question 11. One mole of pure hexane is in vapor liquid equilibrium at 1 atm and 70 °C in a piston and cylinder. After 0.2 mol of *heptane* liquid is injected, the system returns to equilibrium at the same T and P. P^{sat}(hexane) > P^{sat}(heptane) What are the final contents of the system?

A. <u>All liquid</u>

B. All vapor

C. Liquid and vapor with $y_{hexane} > x_{hexane}$

D. Liquid and vapor with $y_{hexane} < x_{hexane}$

Variations on this question

a) Inject heptane vapor instead of liquid.

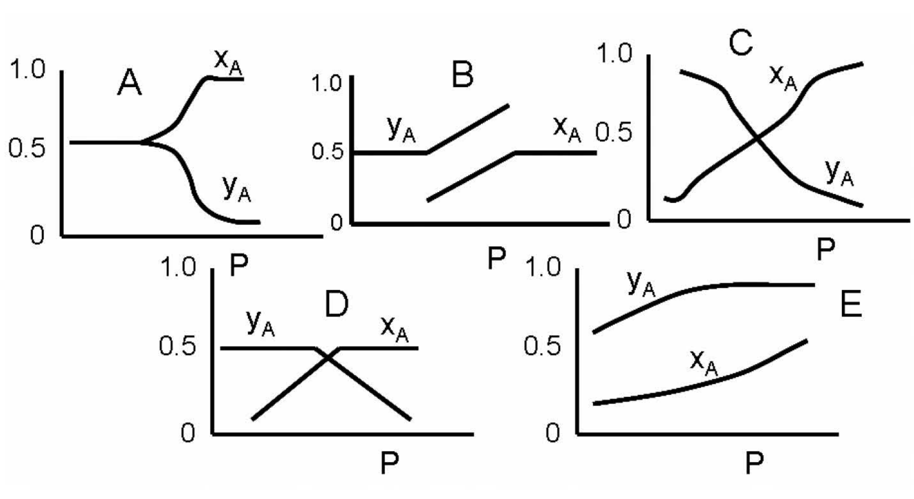
b) Start with pure heptane and inject hexane liquid or vapor.

Question 12. The pressure increases for 50/50 vapor mixture of A and B initially at low pressure. The liquid is ideal. Which plot corresponds to how x_A and y_A change with pressure? $P_A^{sat} > P_B^{sat}$

Correct answer: (b)

Variation on this question

Start with liquid and raise the temperature and show similar plots vs. temperature.



EXAMPLES, CONTINUED

Entropy of Mixtures

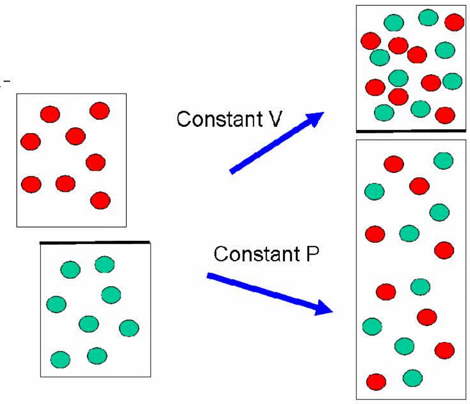
Question 13. Two ideal gases are mixed isothermally. For which of the following does the entropy of the gases increase?

A. constant V

B. constant P

C. both constant V and constant P

D. neither



Fugacity

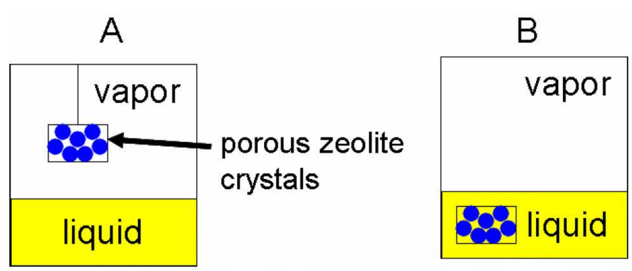
Question 14. Organic molecules adsorb in the pores of zeolites. Consider adsorption from hexane liquid and vapor. The adsorbed hexane concentration in the zeolite pores is:

A. higher in A

B. higher in B

C. the same in both

D. insufficient information



Variations on this question

(a) Use a binary mixture of hexane and acetone, with acetone enriched in the gas phase. Ask which zeolite has a higher concentration of adsorbed acetone.

(b) Use a binary mixture of hexane and acetone, with acetone enriched in the gas phase. For system A, make the liquid 50/50 and for system B make the vapor 50/50. Ask which zeolite has a higher concentration of adsorbed acetone.

Question 15. Two identical flasks at 45 °C are connected by a tube. Flask A contains water, and B contains 50% more water plus it contains ethanol. What happens as the system approaches equilibrium?

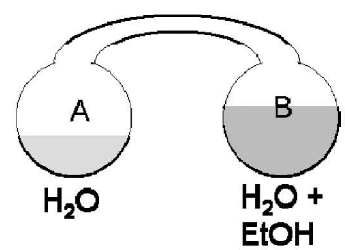
A. Water moves from A to B

B. Ethanol moves from B to A

C. Water moves to B and EtOH to A

D. Both water and EtOH move to A

E. No change in levels



Variations on this question

a) Both flasks contain only water, but at different temperatures.

b) Both flasks contain only water at the same temperature, and then salt is added to one.

Question 16. A can of soda at 0 °C contains liquid water with a low concentration of dissolved CO_2. The gas-phase CO_2 pressure is 1.5 atm. Compare fugacities in the liquid phase.

A. Water fugacity is higher

B. CO_2 fugacity is higher

C. Water and CO_2 fugacities are the same

EXAMPLES, CONTINUED

Chemical Equilibrium

Question 17. For this reaction, Pd and PdO do not mix in the solid phase:

$$Pd(s) + 0.5\ O_2(g) \rightarrow PdO(s)$$

This reaction goes to equilibrium at 400 °C in a *closed container* for two starting conditions:

(a) 100 g Pd, 1 mol O_2

(b) 100 g Pd, 1 mol O_2 , 1 g PdO

The initial O_2 pressure is high enough to reach equilibrium. Which statement is correct?

A. The O_2 pressure is higher for (a)

B. The O_2 pressure is higher for (b)

C. The O_2 pressure is the same for both conditions

Question 18. Calcium carbonate decomposes according to:

$CaCO_3(s)$	$\rightarrow$	$CaO(s)$	+	$CO_2(g)$	
10 mol		0.2 mol		10 mol	initial conditions

At equilibrium, you push down on the piston until the volume is half the original volume.

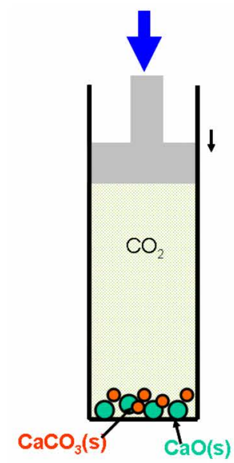
Temperature is constant. What happens?

A. CO_2 pressure almost doubles

B. CaO and CO_2 react; CO_2 pressure does not change

C. At equilibrium so nothing changes

D. All the CO_2 reacts



Variation on this question

Start with 10 mol of CaO instead of 0.2 mol.