

CAN YOU EXPLAIN THIS?

**CONCEPTUAL EXERCISES
FOR PHYSICS STUDENTS**

GENERAL NOTES :

This is the first edition of the *Can You Explain This?* workbook. Although the text has been read and re-read numerous times, you will still find many examples of simple syntax errors, such as 'form' instead of 'from' or 'te' instead of 'the'. The format of the ten chapters may also reveal some slight, unintended variations in spacing, numbering, letter size or centering, etc. If any detail-oriented user of this workbook would like to send me a copy of the text with red corrections all over it, I would appreciate it.

All of these exercises were created by one person and have not yet been class-tested in their current written form – although quite a few of the demonstrations, brain teasers and examples presented in the text have exasperated many of my students in the past. Some of them you will enjoy; others will drive you crazy. Some exercises may be too simple for you; others, you will be convinced, belong only in a calculus-based physics class and no where else. At least some of them should be right on target with the learning objectives of your physics class. When in doubt, I suggest you ask your instructor about the value or usefulness of a particular exercise.

Because this is the first edition, I do not yet have a solutions manual for these exercises. Sorry about that, but that means that you attempt these exercises at your own peril. When in doubt or confused about the appropriate answer, I recommend first discussing your solutions with other classmates, then consulting your instructor, and finally searching through your textbook or other physics resources to determine 'who is right'. But I personally believe that more learning will have occurred if a group of twenty students are absolutely convinced that a certain answer is right – and for the Universe to do the exact opposite – than for an instructor to quickly breeze through the principles behind one of these exercises and move on.

And finally, you will also discover much of my own personal philosophy about learning, science education, and the philosophy of science in these problems. I make no apologies for that; it was intentional. You can agree with my point of view or disagree; you can take it or leave it. But I hope that some of the comments I have put in the mouths of Mr. Nicholls and his students will bear as much fruit in the classroom or among your friends and classmates around a library table as the classic physics brain teasers you are about to tackle, for yourself, for the first time.

Good luck, and above all else, have fun! Life is too short and physics is too interesting not to.

Christopher Wozny
Associate Professor of Physics and Chemistry
Waycross College

INTRODUCTION

What are Conceptual Exercises?

Students taking courses in mathematics or the physical sciences are used to solving word problems. In the traditional word problem, a student is presented with a particular situation and some definite quantities, and then asked to find the numerical value of some other quantity. Here is a simple example of a word problem.

Problem:

Density is defined as the mass of a material divided by its volume. If the mass of a piece of metal is 5.00 grams and its volume is 3.00 mL, what is the metal's density?

Solution:

$$D = m/v$$
$$D = 5.00 \text{ g} / 3.00 \text{ mL}$$
$$D = 1.66 \text{ g/mL}$$

The purpose of a word problem is to assess if a student understands the ideas, principles and equations learned in class by applying them under a specific set of conditions. In addition, working through word problems often helps a student learn the basic principles of science or math through practice.

Word problems are a useful and important method of assessment, but they are not the only approach. Conceptual exercises are an equally valid method of student assessment. Like the traditional word problem, a conceptual exercise begins with a particular situation and a set of facts and conditions relating to it; but unlike a word problem, the solution to the problem is not intended to be a particular number or value. Here is an example of a conceptual exercise on density:

Problem:

The density of water is 1.00 g/mL. The density of cooking oil is 0.89 g/mL. When poured into the same container, will the water float on top of the oil; or will the oil float on top of the water?

Solution:

The more dense substance sinks to the bottom, and the less dense substance rises to the top.

Water has a density of 1.00 g/mL and oil has a density of 0.89 g/mL.

Based on this information, water is more dense than oil, so water will be the bottom layer and oil will be the top layer — oil floats on water.

Even though the previous problem included numbers, the purpose of the problem was *not* to manipulate the numbers using arithmetic or algebra. As with algebraic word problems, equations may also be useful when answering conceptual exercises, even if no calculations are made with the equation.

No Guessing!

When students first encounter a conceptual exercise, the tendency is to make a guess at an answer *without any reasonable explanation*. For example, when given the oil-water conceptual exercise as a homework problem, students will often state ‘the oil will float on water’ or ‘water floats on oil’ with no further explanation. But the purpose of a conceptual exercise isn’t just to write down a correct answer; it is to understand the scientific principles that the exercise is illustrating. The same is true of word problems. Imagine a student who gave an answer of 15.0 g/mL to the density word problem presented above. When asked how he arrived at the answer, his response may be, ‘Well, everyone knows that three times five is fifteen, so the answer must be fifteen.’ Would that answer, based on no logic or appropriate equations, be any more or less acceptable than the statement, ‘water floats on oil, because everyone knows that water floats on oil’ (which, by the way, is incorrect)?

A guess may be a necessary starting point for a conceptual exercise (what are the *possible* solutions to this problem?) but it can’t be the ending point. A guess is often confused with a hypothesis. A hypothesis is an *educated* guess, or a guess with a reason. Both hypotheses and wild guesses must be measured by the specific information and circumstances given in the problem. The answer to a conceptual exercise is *not complete* until a series of logical statements can be made based on correct and appropriate science concepts or principles connecting the conditions and circumstances set forth in the exercise to the final solution.

How to Use This Workbook

This workbook of conceptual exercises has two purposes: one is help students understand important physics concepts and principles; the second is to help students develop the problem-solving skills needed to solve conceptual exercises consistently and correctly. I believe one reason why we may guess at answers to problems is that we can’t see any connection between the problem set-up and the possible solutions. The exercises presented here have been designed to make the path to the correct solution as clear as possible.

Each chapter of the workbook examines a different physics topic encountered in a general physics or technical physics course, and each unit has three different types of conceptual exercises.

The first type of exercise is titled *Conflicting Contentions*. After setting up the particular conditions of the conceptual problem, these exercises usually present both the possible solutions and the reasoning that led to them. There is no need to make any wild guesses with most of these exercises: that has already been done for you!

Obviously, not all of the answers can be correct – and it may be that none of them are correct. Your task is to determine why an argument is unreasonable. It may be that a particular statement is simply incorrect. It may be that the argument is based on a physics principle that doesn't apply to that situation. Or perhaps there is a condition in the problem that was assumed – or perhaps information that was overlooked.

The second type of problem, *Qualitative Reasoning* questions, come closest to the density exercise presented in this Introduction. These exercises usually involve a comparison between situations with slightly different conditions. For example, an object may be twice as massive as another, or may be traveling with twice the speed of another. The purpose of this type of exercise is to help you connect a general scientific principle to real, specific conditions.

The third set of exercises in each chapter are called *Can You Explain This?* or C-YETs (See yet?). Once again, the need to guess at the answer is reduced because the correct answer is already given in the exercise. As with the other problem types, the goal is to develop a reasonable and accurate explanation for the behavior described by the situation which is based on the correct physics principles that apply in that situation.

Your instructor will have his or her own opinion on how to best use these exercises. You may notice that all of the exercises come in sets of three or six of each type per chapter. In order to develop scientific reasoning skills, I recommend that the solution to one *Conflicting Contentions* exercise (usually the first one) and two problems of the other two types be presented and discussed in class by the instructor. A few of them have already been written that way: under the section entitled, *The Answer*. This method is similar to the 'Solved Word Problems' often found in a textbook. In the same way, just as half of the end-of-the-chapter word problems have the answers in the back of the book, I recommend that another third of the problems have answers that you can check *after* you have tried the problems on your own. The remaining one third of the problems could be submitted for grading or points, if your instructor would like to try this approach.

Meet the Physics Class

Concepts are ideas, and ideas are best understood through shared discussion. Usually, we don't truly understand an idea until we have had a chance to ask questions about things that confuse us and our compare ideas with those of other students and the instructor. Of course, it isn't possible for me to present these exercises to your class directly, so instead I am inviting you to participate in a 'virtual' class that I have created just for you.

Your instructor for this virtual physics class is Mr. Nicholls. He doesn't like to lecture very much; instead, he prefers students learning physics by exploring the world around them. His motto is: 'Don't tell students something if you can show it to them, and don't show it to them if they can do it themselves.' As you will discover, Mr. Nicholls has quite a collection of physics demonstrations. He also has the exasperating habit of not answering students' questions but making them figure out the answer for themselves.

Alonzo is an electrician in his late thirties. He is married and has two teenage daughters. His company has encouraged him to go back to school and get more education, with the goal of giving him a promotion when he is done. He takes a very practical approach to science, and is usually among the first to offer a possible solution to one of Mr. Nicholl's demonstrations. He isn't afraid to suggest an answer that may be wrong. He knows that you always have to start somewhere, and it isn't important where you start but where you end up.

Beth is eighteen years old and just graduated high school. Her career goal is to become a respiratory therapist. She is the type of student who will write down everything the teacher says in class, and then later re-write her notes, color-coding them with a four-color pen. She is always punctual and likes everything to be exact and in place. Mr. Nicholls drives her crazy.

Cathy is Beth's best friend. She thinks she may want to be a nurse, but she is not quite sure. She is taking the physics class because Beth asked her to and she thinks that maybe the course were help her decide on a career. Cathy's biggest problem is her lack of self-confidence: unlike Beth, she never had a physics course in high school. Mr. Nicholls, quite wisely, usually makes Beth and Cathy have other partners when they do labs and experiments.

Daniel is in his mid-twenties and very easy-going. He worked at a number of different minimum wage jobs right after high school, and now he is ready to get serious about a career. He isn't quite sure what he wants to do, but he's thinking about industrial management. Physical science was one of his best subjects in high school, so he decided to take the physics class. Daniel is sharp enough, but he has trouble applying himself. He is always late to class.

Frank is an explorer; he just can't keep his hands off the equipment. He is also a recent high school graduate and he is curious about everything. He thinks he might want to be a mechanical engineer but his parents aren't willing to pay for an expensive university education until he makes some definite decisions about his future. That's okay with Frank; right now he is happy with what he is doing. Frank's advisor suggested taking Mr. Nicholls class instead of starting with the calculus-based physics course. His advisor believes Frank might be happier in a technical career instead of engineering.

John and *Mary* are husband and wife. John has a Bachelor's degree in business; Mary never went to college before but runs her own business. John is thinking about a career change and wants to 'try physics'. Mary is taking the class so that the two of them can do something together without the kids. Mary is also thinking about giving up the business and working for one of the companies in the industrial park, where she would have more job security. She believes the physics class might make her more employable.