# RANKING TASK EXERCISES IN PHYSICS

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## *Foreword*

Thirty years of careful study by physicists and others interested in education reveals that students enter our introductory courses with conceptual beliefs that differ considerably from the accepted concepts of physics. Unfortunately, a good fraction of these same students leave our courses with their alternative beliefs unchanged. Because of these studies, there is now more interest in helping students build a better conceptual foundation for their studies in physics.

Building this foundation is aided by uncovering students' alternative beliefs, a task well-suited for Ranking Tasks. A ranking task provides a question with several contextually similar situations. The situations differ in the value of one or more physical quantities (number of parallel or series bulbs, speed and mass of a swinging object, and so forth). The student ranks the situations according to some other physical quantity (electric current, rope tension and so forth). The student also provides reasons for their ranking. The ranking order and the explanation provide a window into the student's mind and helps a teacher or professor identify different models for what students are thinking.

Ranking tasks are also very useful for helping students modify their conceptual beliefs. Students are given a ranking task. The student completes the task working alone. The student then compares their thinking with that of another student and tries to reconcile any differences in thinking. The ranking task serves as the focus for a small group or classroom discussion. The tasks can also be given as homework problems and on quizzes and exams.

The present set of materials was developed during a series of workshops for two-year college physics professors which was supported by the National Science Foundation and organized and facilitated by Curt Hieggelke and Tom O'Kuma. David Maloney, the inventor of Ranking Tasks, was a co-leader for one series of these workshops. David taught participants how to use ranking tasks and then asked them to develop one or more tasks. Participants found the use and development of these tasks a valuable and enjoyable part of these intensive three-day workshops.

Do they make a difference? The gains of workshop participants' students on the Force Concept Inventory conceptual test and on the Mechanics Baseline problem-solving test have been excellent (see for example, TO-C and M-PD95b-C in Figure 4 on page 68 of Hake[1]). Curt Hieggelke's students, who use ranking tasks extensively, have some of the highest scores on the recently developed Conceptual Survey of Electricity and Magnetism. Perhaps more important is the ease with which faculty can learn to use and develop ranking tasks.

The authors (O'Kuma, Maloney and Hieggelke and the many talented two-year college professors who contributed to this book) have provided us with a rich resource of learning activities. Give them a try—you'll like them.

Alan Van Heuvelen

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[1] R.R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64-74 (1998).

## *Preface*

On November 21–23, 1991, a workshop for two-year college physics teachers on Conceptual Exercises and Overview Case Studies was held at Joliet Junior College, Joliet, IL. This workshop was the first of many such workshops conducted as part of the Two-Year College (TYC) Physics Workshop Project, which was sponsored by Joliet Junior College, Lee College (Baytown, TX), and a series of grants from the Division of Undergraduate Education of the National Science Foundation. At one of the sessions in this workshop, the participants, working together in groups of three or four, constructed ranking tasks and then presented them to the larger group for feedback and response. (A ranking task is a conceptual exercise created by David P. Maloney as one of the many ways to ascertain a student's understanding of concepts.)

During the 1991–98 period, the TYC Physics Workshop Project continued to hold workshops during which a variety of ranking tasks for introductory physics were developed at or as part of the follow-up activities after the workshop by the participants. During the academic year 1993–94, the ranking tasks that had been developed as part of the TYC Physics Workshops were categorized and put into electronic form at Lee College. These were called *A Collection of Physics Ranking Tasks* and were distributed to previous workshop participants in May 1994. During the academic year 1994–95, a subset of these ranking tasks and newly developed ones were further refined and widely distributed by Joliet Junior College as *A Selection of Physics Ranking Tasks.* This book is a revision and expansion of that book.

Although these materials are copyrighted by Prentice Hall, professors have the right to use the materials for noncommercial educational purposes and can copy or have copied the materials in the book for the students in their classes. However, these materials, whether in their original or in an altered form, may not otherwise be distributed, transmitted, or included in other documents without express written permission from the publisher. We have included a CD with this book that has a pdf version of each ranking task exercise in 8 1/2 x 11 format to further facilitate professors' use of these materials in their own classes, workshops, or for any noncommercial use. If you do not already have Adobe Acrobat Reader, please contact Adobe's web site (http://www.adobe.com), where it can be downloaded for free. This software will allow you to print and/or modify these ranking tasks.

In the first section, we have included some background material, including sample and practice ranking tasks, which give students an understanding of this type of instrument, and examples of how to complete a ranking task. The main body of ranking tasks is divided into broad topical areas, with mechanics in the first section. The second section includes properties of matter, heat and thermodynamics, and waves. The third section covers electricity and magnetism. And finally, we have included an answer key for this edition.

You are invited to visit our web site for corrections, updates, and additional ranking tasks (http://www.tycphysics.org). If you have any questions about these ranking tasks, please contact us.

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Next, we want to give special thanks to the National Science Foundation for their support of the Two-Year College Physics Workshop Projects. We thank the many program directors at NSF that have supported this project, especially Duncan McBride, William Rauckhorst, William Kelly, Ken Krane, Ruth Howes, J. D. Garcia, Jack Hehn, and Karen Johnston.

At Joliet Junior College we particularly thank and acknowledge the support of this project by Michael Lee, Chairman of the Natural Science Department; Vice Presidents James Lepanto, Denis Wright, and J. D. Ross; and Presidents Raymond Pietak, Thomas Gamble, and J. D. Ross.

In addition, at Lee College we want to give special thanks to Wayne Miller and Carolyn Foster, Division Chairs of the Math, Science, and Engineering Division; Dean Donnetta Suchon; and Presidents Vivian Blevins and Jackson Sasser.

We want to thank Karen Dailey, who spent considerable time converting hard copy ranking tasks into electronic form at Lee College. We are also grateful for the assistance in various areas of this book by David Pequeno, Reggie Delgado, Regina Barrera, Sherry Green, Greg Gober, and Kathy O'Kuma.

At Joliet Junior College, we want to thank Craig Sumner, who reworked many diagrams, bringing them into final form. We also appreciate the help at different stages in this book by Jan Coleman, Judy Bond, Aaron Stone, Matt Kelly, Steve Clark, Eric Manuel, Geoff White, and Gale Ruggiero. Also, special thanks to physics professors Joe Krivicich (Joliet Junior College), William Hogan (Joliet Junior College), and Duane Desbain (Highland Community College, Highland, KS), who reviewed many of these ranking tasks.

We also want to thank our students, who tried out these ranking tasks and provided us with valuable feedback.

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Finally, we thank Alison M. Reeves at Prentice Hall, who supported this project and the publication of this book.

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## *Background, Insights, and Uses*

This book is intended as a resource for physics instructors who are looking for tools to incorporate more conceptual analysis in their courses. In putting together this collection of ranking tasks (RTs), we have been guided by two major goals.

First, we wanted to provide instructors with a set of immediately useful RTs from as many topic domains in physics as possible. Although the number of RTs on different topics is not uniform, this collection does contain RTs from all topics of classical physics except for optics. (Optics has proven to be a topic for which it is difficult to design good conceptual ranking tasks.) The RTs in this manual can be copied directly from the manual and used immediately in the classroom. Or an instructor can quickly modify one of the items in the book to fit his or her style and context.

Second, we wanted to illustrate a wide variety of RTs so that instructors could get an idea of the flexibility of the format and ideas about how to generate RTs for themselves. Generation or examination of a ranking task will often suggest an easily produced variation or variations. Student responses to a ranking task are another good source of ideas for other RTs. We hope that seeing a range of variations for a variety of RTs will enable instructors to develop sufficient familiarity with RTs so that they will be able to develop their own. Constructing good ranking tasks is not easy, but interested instructors should be able to generate viable ones with some practice.

### Nature and Structure

The idea of ranking tasks arose from research into students' conceptions using a technique called rule assessment, developed by Robert S. Siegler (1976). The rule-assessment technique involved having subjects make a comparative judgment about a large variety of arrangements of a specific situation. The ranking tasks were conceived as a shorter format for eliciting such comparative judgments.

A ranking task is a paper-and-pencil exercise that presents students with a set of variations on a particular physical situation. The students are supposed to rank the variations on a specified basis. After explicitly writing out their ranking sequence or choosing the option that all of the variations are equivalent, the students are asked to write out an explanation of their reasoning. Finally, students are given an opportunity to identify how sure they were of the reasoning they used in the task.

As explained in the original ranking tasks article (Maloney, 1987) the basic structure of RT has four elements: the description of the situation, including the constraints and the basis for ranking the arrangements; a set of figures showing the different arrangements to be compared; a place to identify the response sequence chosen or to indicate that all of the arrangements have the same value for the ranking basis; and a place to explain the reasoning for the answer produced. Many of the RTs in this book have an additional element–a scale at the bottom of the page for the students to indicate how sure they were about their answers. This can be useful in at least two ways. First, it can tell an instructor how strongly the students are consciously committed to their ideas. Second, many students often feel that they are "just guessing" when they answer the RT, and that is what they want to write for their explanation of the reasoning. Having the scale at the bottom of the page provides an outlet for the students to express these feelings so they can use the explanation section to describe what they actually did when working the task.

Ranking tasks contain few clues about how they should be worked. In addition, they require students to think about the situations in an unusual manner. Usually students deal with such situations in physics by calculating a specific numerical value given a limited number of other numerical values, all of which are normally needed in the calculation. In a ranking task students are confronted with a set of variations that usually differ in the specific values for two variables, and they have to decide how these variables affect the behavior of interest of the system.

Although most of the ranking tasks in this manual contain numerical values for two variables, we think of RTs as conceptual exercises. One might wonder how this works. The reason for our contention is that experience has shown that students often use the numerical values in inappropriate ways. Such use reveals one of several problems. One common problem is that the students do not understand the relations they are using, but rather just know to plug whatever numerical values are available into whatever relation is available. A second common problem is for students to apply the wrong relation to the situation. An example of this difficulty is students' strong tendency to use the product of mass and speed when they actually need to use the kinetic energy. So having the students use the numerical values in inappropriate ways can provide insight into their concepts and strategies.

The RTs in this manual vary widely in a number of ways. One way in which they vary is in how much computation is required to do a task. There are several reasons for this variation. One case is the "Two Different Blocks and a Pulley–Net Force" task on page 30, where students need to set up Newton's second law for the two masses and solve the equations simultaneously. Students seldom approach this task in this manner, but they also lack an equation they can quickly apply, so presenting them with such a situation makes them generate a procedure. It is often useful to see what students do with such a task. Sometimes we do want the students to learn how to do certain calculations, e.g., "Five T's Rotating About an Axis (top view)–Angular Acceleration" on page 94. And in some cases students need to do the calculations to understand that apriori ideas (e.g., symmetry considerations) don't always work out.

## Reasons for Using Ranking Tasks

A fairly obvious question at this point is why an instructor would want to use ranking tasks. One strong reason for using them is the fact that they frequently elicit students' natural ideas about the behavior of physical systems rather than a memorized response. This ability of the ranking tasks to elicit students' natural ideas provides instructors with a way to gain important insights into students' thinking. With the help of those insights the instructor can help the students adapt to the scientifically accepted ideas.

Research in physics education (Clement, 1982; Peters, 1982; Halloun and Hestenes 1985; McDermott, 1991) has demonstrated that it is often difficult to get students to change their natural ideas about the physical world. A productive part of any effort to change students' ideas can be getting them to consider the same idea in a variety of ways. In a sense we want to be able to ask the same question in a variety of ways. Ranking tasks are a useful tool in such an effort, since they provide a way to frame questions in a manner that is novel for almost all students. Subsequently showing the students that they have responded in a different way to the same question asked in different ways can be useful for getting them to think about why they responded as they did in each case. That, in turn, can lead them to think about which, if either, response they believe in more strongly and why.

Another important reason for using RTs is that they can be used to reframe a question asked in a traditional problem, or a multiple choice item, or an essay, but in a different way. So RTs can be used to determine how robust a student's concept is. Students get used to responding to multiple choice items, and they often develop coping mechanisms that allow them to respond to such items without really thinking the situation through. Couching the same question in a different format, which requires a different way of evaluating the situation, makes the students think about the concepts, principles, and relations in another way.

We have found that certain RTs are excellent for helping students develop legitimate understanding of some concepts. For example, there are a number of ranking tasks in this book involving uniform electric fields. It has been our experience that if students are not asked about uniform electric fields, they have definite misconceptions about them. However, after some work with ranking tasks, such as those in this book, most students develop a robust understanding of this issue. We believe that there are a number of ideas for which well-designed ranking tasks are an especially effective way to help students learn.

## Uses

Ranking tasks are useful in a variety of ways. They make good homework assignments and good test questions. Ranking tasks are a good "size" and form as homework assignments because they are simple and easy for the students to understand but require careful and thorough analysis for correct completion. But RTs can be made challenging enough that they can even be assigned as homework where the students are allowed (encouraged) to work together. An example of such an item is "Circuit with Three Open and Closed Switches–Voltmeter Readings I" on page 186.

As test items RTs provide two parts–the ranking sequence and the explanation–that can be scored separately; for example, 2 points of 5 for the correct ranking sequence and 3 of 5 for a correct explanation. RTs are usually challenging test items for students. When using RTs as test items it is often best to have only four or five variations so that the students do not spend too much time, and/or make silly errors, with the calculations.

Ranking tasks are also very useful if an instructor wants to generate class discussions or have students engage in peer instruction or group work. A productive way to generate a class discussion is to give the class a ranking task, allow them about 5 minutes to work it, have them talk to each other about their solutions, and then ask selected individuals to present their answers. The instructor can then either have these students defend their ideas, assuming conflicting ideas have been presented, or can talk about the ideas and how to reason to the correct response. Giving ranking tasks to the students, who have been assigned to small groups, and telling each group that they have to come to a consensus about the answer is another good way to use RTs.

Sets of related tasks are also good for class discussions. Tasks can be related by having different objects exhibiting the same physical behavior, e.g., an arrow, a stream of water, and a rock undergoing projectile motion, by changing the variables for the situation, e.g., mass and speed, mass and height, or speed and height for a ball thrown off a building, or by a number of other modifications of a situation. After the students work individual RTs from the related set, the students can be grouped by the particular version of the task they worked to discuss their answers. (This assumes the class is small enough for them to move around the room.)

Ranking tasks can be used to pre- and posttest students to check on the extent to which their ideas have been changed by instruction. Since RTs often bypass students' memorized physics ideas, they are especially useful in determining the extent to which instructors have been successful in changing students' natural (common sense) beliefs about physical situations.

The first time students are presented with ranking tasks, we suggest first giving them one of the sample ranking task pages. Give them an opportunity to read through the page carefully and check to see if they have any questions about how to work these tasks. Then we suggest passing out the practice RT and having them work it. Go over the answer, emphasizing explicitly showing how ties in the answer sequence are indicated and writing a complete explanation.

There is one very important point about using RTs in situations where students will earn credit for doing them. Since RTs are unfamiliar to students, it is critical for the students to have an opportunity to practice with the format in a noncredit context first. This is important to assure that students explicitly show ties and that they write complete explanations.

## Related Ranking Tasks

If an instructor decides that they want to generate their own ranking tasks, a good way to start is to generate a variation on an existing task. There are several ways to vary existing tasks to produce new tasks.

One way is to have students rank the same situation on a different basis. An example of this technique is found in the "Cars and Barriers–Stopping Distance/Time with the Same Force" tasks on pages 62 and 80. In a similar way it is often possible to ask the same question in different ways. An example of this is "Carts Moving Along Horizontal Surface" on pages 17 and 18. This approach is especially useful when one version of the question uses the technical language of physics while the other employs natural, everyday language. Another related technique is to ask the same question but have different variables for the students to work with.

A different approach is to have the same variables and question but vary the physical situation. An example of this is shown in "Horizontal Arrows," "Rifle Shots," "Toy Trucks," and "Spheres Thrown Horizontally Off Cliffs" tasks on pages 48 – 51. All of these are the same projectile motion situation, however, students often think that different physical systems will behave differently. Getting students to see past these noncritical surface features to the physical principle that applies is an important aspect of learning to do physics.

Another very important aspect that can be varied is the representation used for presenting the information. An example of this is shown in "Uniform Electric Field—Electric Force on Charge at Rest" tasks on pages 150–152. Students often learn information in one representation, i.e., they will know what to do if given a kinematic equation, but will be lost if the same situation and information is presented in graphical form. Ability to handle tasks represented in various ways is a good indicator of solid understanding.

It will be easier to construct variations for some situations, concepts, or principles than for others. And for some situations, concepts, or principles students may need to work through a wider variety of those variations in order to develop a solid understanding. Our experience indicates that the topic of sinking, floating, and buoyancy is one topic where a wider variety of tasks is useful. Consequently, both to present ideas about generating related RTs and to give a specific example of how to approach such a topic, there is what will probably seem to many a large number of RTs on sinking, floating, and buoyancy.

A unique contribution to this book is the Resistive Circuits Concepts Diagnostic Test developed by Dennis Albers. This test is a sequence of ranking tasks on basic electric circuit concepts. In a way this test takes the idea of using related ranking tasks to the extreme, but having this set of interrelated ranking tasks enables an instructor to get a clear understanding of students' ideas about simple electric circuits. Similar tests could obviously be developed for other physics topics.

Finally some other ideas for different types of RTs, such as using comparative values for variables rather than specific numerical values and other ways to develop tasks that involve three variables, can be found in Maloney and Friedel (1996).

In writing RTs we believe there are several issues that should be carefully considered. First, we believe instructors should take account of known, or suspected, student alternative conceptions when developing an RT. Because RTs frequently elicit students' natural ideas, using those ideas in writing the RT can make it a better conceptual exercise. A second issue is the language—natural, i.e., everyday, versus technical—used in the RT. If one wants to elicit students' common-sense ideas, then natural language is usually more effective. But having students respond to the same task written in natural and technical language can be a useful exercise. A third issue is how many variations to present in the RT. In some situations this can be fixed by the situation, which may have a fixed number of variations. In most other cases the number of variations to include is usually tied to how the RT is to be used. As a homework assignment, eight variations might be chosen to provide practice in calculating and evaluating alternatives. For a test item, between four and six variations are more reasonable.

The editors would appreciate feedback about the items in this book. We are especially interested in learning about other variations and uses of ranking tasks and about new RTs. We would also like to hear about any errors that may have crept in despite our best efforts to ensure that everything is correct.


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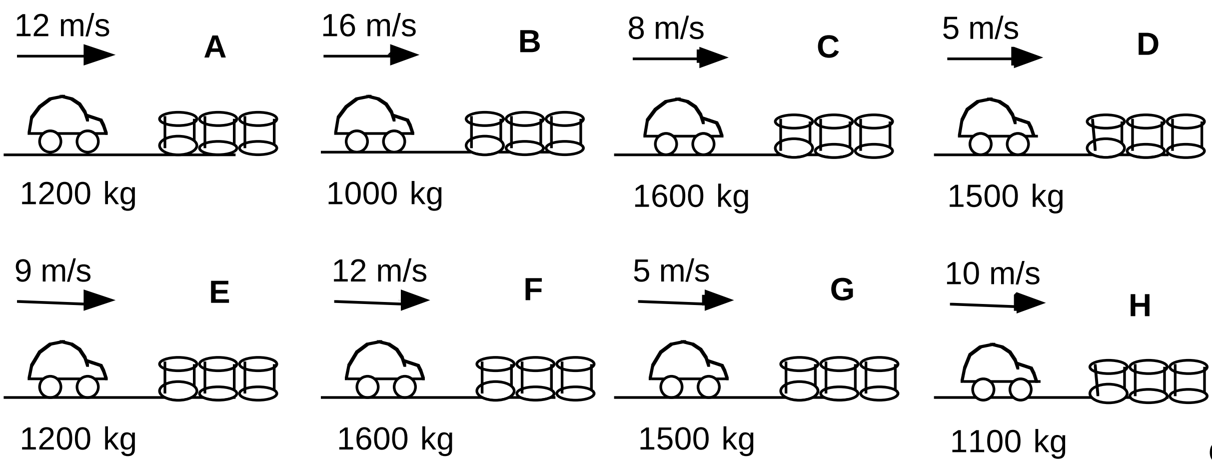
## *Ranking Task Sample I*

For a ranking task, each item will have a number of situations as illustrated. Your task will be to rank the items in a specific order. After ranking them you will be asked to identify the basis you used for the ranking and the reasoning behind your choice. It is extremely important that you are careful to write out the proper ranking once you have determined what basis you are going to use, i.e., make sure all of the situations are ranked in the proper order according to your basis. The sample below shows how to rank items and what your explanation should be like. **NOTE: Although the procedure for working the item is correct, the particular answer, which was chosen at random from actual student responses, may not be correct.**

**Example:**

Shown below are eight cars that are moving along horizontal roads at specified speeds. Also given are the masses of the cars. All of the cars are the same size and shape, but they are carrying loads with different masses. All of these cars are going to be stopped by plowing into barrel barriers. All of the cars are going to be stopped in the same distance.

Rank these situations from greatest to least on the basis of the strength of the forces that will be needed to stop the cars in the same distance. That is, put first the car on which the strongest force will have to be applied to stop it in x meters, and put last the car on which the weakest force will be applied to stop the car in the same distance.




Greatest

1_B_ 2__A F__ 3____ 4_H__ 5_E___ 6_C__ 7_D G_ 8____ Least

Or, all cars require the same force. ________

Please carefully explain your reasoning

*Since acceleration is the change in velocity divided by the change in time and all the changes in times are the same, then I used the change in velocity.*

How sure were you of your ranking? (circle one)

| Basically Guessed | | | | | Sure | | | Very Sure | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Notice in this example that two situations produced the same result for the ranking and that these were listed in the same answer blank. Such a possibility exists for all items. In the same way, it is possible that all of the situations will give the same result. If that occurs, and only if that occurs, the option of all equal, or all the same, should be chosen.

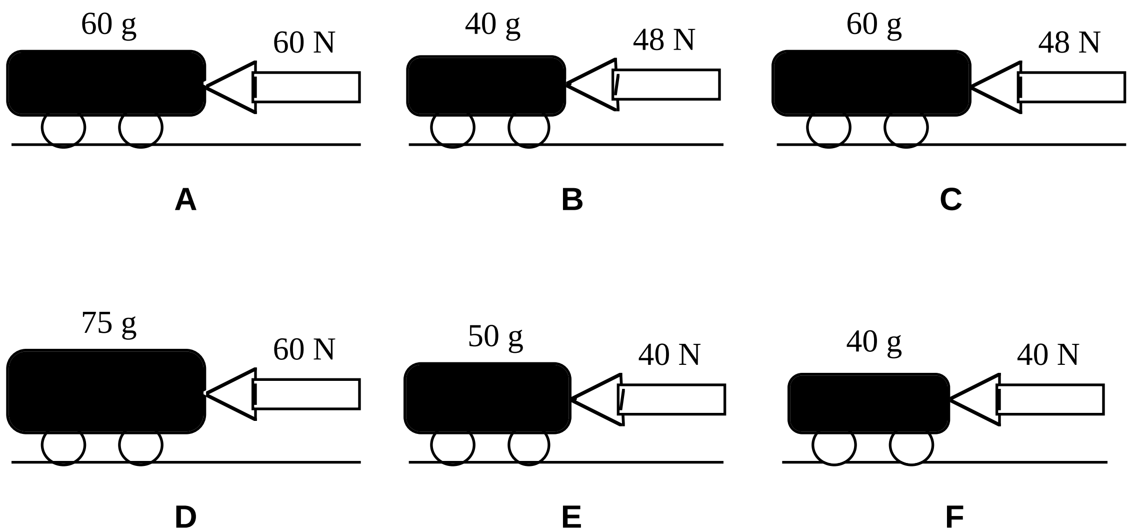
## *Ranking Task Sample II*

Each ranking task will have a number of situations, or variations of a situation, that have varying values for two or three variables. Your task is to rank these variations on a specified basis. After ranking the items, you will be asked to explain how you determined your ranking sequence and the reasoning behind the way you used the values of the variables to reach your answer. An example of how to work the ranking tasks follows.

**Example:**

Shown below are six situations where a cart, which is initially moving to the right, has a force applied to it such that the force will cause the cart to come to a stop. All of the carts have the same initial speed, but the masses of the carts vary, as do the forces acting upon them.

Rank these situations, from greatest to least, on the basis of how long it will take each cart to stop.




Greatest 1__B__ 2__A__ 3__F__ 4__C__ 5__D__ 6__E__ Least

Or, all of these carts will require the same time to stop. _______

Please carefully explain your reasoning.

*I think the time depends on the acceleration, so I divided the forces by the masses.*

How sure were you of your ranking? (circle one)

| Basically Guessed | | | | | Sure | | | | Very Sure |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

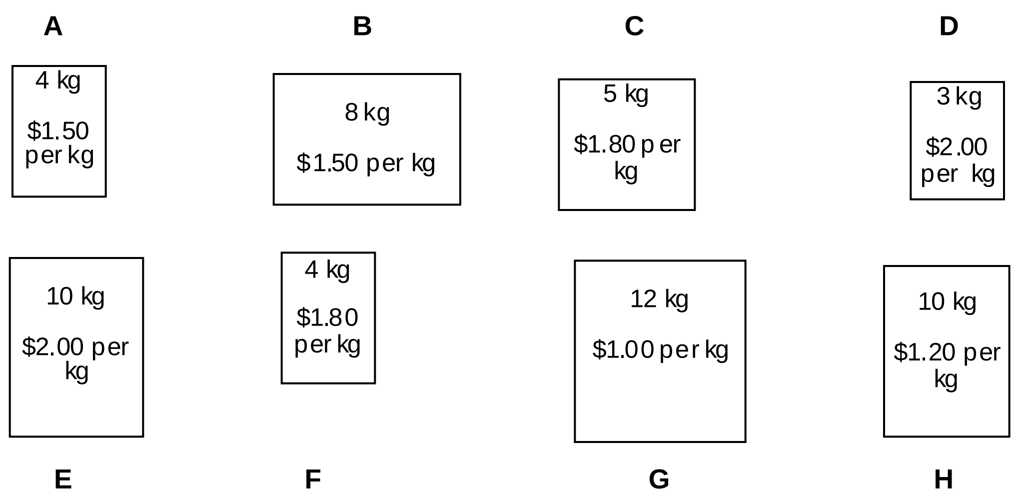
Notice in this example that in one instance, two of the situations produced the same value of the ratio used to determine the ranking, and that the letters for the ones that tied are circled showing they were ranked equally (A and F). In another instance, three of the remaining situations have the same ranking and they are circled together (C and D and E), showing this result. In the same way, it is possible that all of the arrangements will give the same result for a particular basis. If that occurs, and only if that occurs, the option of all equal, or all the same, should be chosen.

## *Practice Ranking Task*

The purpose of this page is to practice an exercise known as a ranking task. Each ranking task will have a number of situations, or a number of variations of a situation, that have varying values for two, three, or four variables. Your task is to rank these variations using the basis specified in the problem statement. After ranking the items, you will be asked to explain how you determined your ranking sequence and the reasoning behind the way you worked the item as you did. In addition, you should indicate your confidence in your ranking and reasoning. Notice that *it is very important to show such ties explicitly*! It is possible that all of the variations could have the same value on the ranked basis. If that occurs, *and only if that occurs*, you should choose the all equal, or all same, option.

**Example:**

Shown below are eight rectangles representing containers of coffee. These containers were purchased by eight people at various stores. The price per kilogram and the mass of coffee purchased by each person are specified in each figure.




Rank these containers, from greatest to least, on the basis of how much each person paid for their coffee. That is, put first the container that cost the most and put last the container that cost the least.

Greatest 1_____ 2_____ 3_____ 4_____ 5_____ 6_____ 7_____ 8_____ Least

Or, the cost was the same for all of these containers _____

Please carefully explain your reasoning:

How sure were you of your ranking? (circle one)

| Basically Guessed | | | | Sure | | | | Very Sure | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |