Physics 103: Effects of using context rich problems in Physics 103 discussions

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Abstract

Physics education research at the University of Minnesota and the University of Washington indicates that students in introductory level physics classes perform better and rate their overall learning amount higher when they participate in context rich problem solving on a regular basis. This project utilized research and implementation strategies by these two universities to investigate how students in Physics 103 at the University of Wisconsin were affected by such problem solving. During biweekly discussion sessions the study engaged half of the sections in context rich problem solving and the other half of the students in traditional textbook problems. Students' midterm scores were correlated with the type of discussion they participated in, and no statistical difference between their scores was found. A number of reasons why this might have been the case are discussed.

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1. Definition of Problem

1.1 Physics 103: A need for change

Large universities such as the University of Wisconsin face the challenging task of providing large numbers of students with a quality education, especially given the rigid logistical structure and low professor-to-student ratio at most universities. In addition, there is often a discrepancy between what professors think students should take away from their class and what students actually learn. According to Lillian McDermott, an authority on physics undergraduate education, "Results from research indicate that at all levels of instruction the difference between what is taught and what is learned if often greater than most instructors realize."[1]

Physics 103 at UW-Madison is the first semester of non-calculus based introductory physics. The students taking this class are primarily taking it because it is required for majors like zoology, pre-pharmacy, and biology.

Past student reviews have shown the majority of students to be dissatisfied with the class, in fact many of them have voiced strong opinions about their dislike for 103. Class evaluations for 103 are consistently lower than other classes in the physics department. This is cause for concern because a solid science education is important for making wise decisions in modern society. The National Science Education Standards say,

> Scientific literacy also is of increasing importance in the workplace. More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the processes of science contributes in an essential way to these skills. Other countries are investing heavily to create scientifically and technically literate work forces. To keep pace in global markets, the United States needs to have an equally capable citizenry.[2]

While science education is certainly valued by the university, it is unclear whether the current means of physics instruction in the 103 classroom are meeting this goal. Students commonly complain about the irrelevance of this course and score poorly on the conceptual questions.

In a society in need of scientifically minded citizens in all areas of expertise, it is advantageous to study possible means for improvements in the physics 103 course. This study aims to investigate a discussion method recommended by physics education research groups at the University of Minnesota to determine whether this method is a valid avenue for increasing student understanding of the 103 course material at the University of Wisconsin.

1.2 Research Objective

This study uses an active research method to determine whether modified discussion material involving context rich problems (CR), as defined by the University of

Minnesota, instead of traditional textbook problems improves student understanding of the introductory physics material.

1.3 Introduction to context rich problem solving

Like many large universities, the University of Minnesota has a discussion/recitation element to their introductory courses where students solve problems in small groups. The effectiveness of this approach has been shown and is widely accepted and promoted in physics education literature. After years of evaluating their discussion groups, the University of Minnesota came to the conclusion that there are four main elements that need to be included in effective group problems.

- The problems need to be challenging enough that a single student cannot solve it, but not so challenging that a group cannot solve it.
- The problems need to be structured so that the groups can make decisions on how to proceed with the solution.
- The problems should be relevant to the lives of the students.
- The problems cannot depend on students knowing a trick nor can they be mathematically tedious.[3]

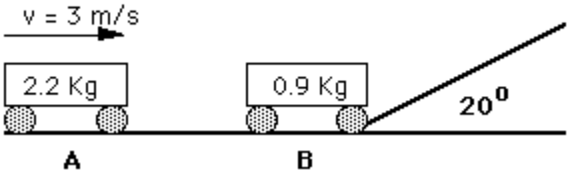
To meet this need the University of Minnesota has created a category of problems they call “context rich problems” which include the above characteristics. According to the University of Minnesota, traditional textbook problems do not often meet all of the above criteria and they often include common pitfalls such as those listed below.

- Unreal objects that do not tie physics to the real world.
- Physics is clearly spelled out for the students hence robbing the group of an important decision.
- Assumptions are clearly spelled out again robbing the groups of a decision.
- A picture is included which denies the group a decision
- Variables are pre-defined for the students.

For these reasons, they have deemed such textbook problems “inappropriate for group work.” In response to the need for more effective problems, the University of Minnesota has generated a guideline for writing context rich problems (see Appendix A) and one for evaluating the difficulty of a problem (see Appendix B). The follow example from the University of Minnesota illustrates the difference between traditional problems and context rich problems.[4]

Traditional Problem

Cart A, which is moving with a constant velocity of 3 m/s, has an inelastic collision with cart B, which is initially at rest as shown in Figure 8.3. After the collision, the carts move together up an inclined plane. Neglecting friction, determine the vertical height h of the carts before they reverse direction.



The following context rich problem is the same problem, only it avoids the pitfalls of the traditional problem.

Context Rich Problem

You are helping your friend prepare for her next skate board exhibition. For her program, she plans to take a running start and then jump onto her heavy duty 15-lb stationary skateboard. She and the skateboard will glide in a straight line along a short, level section of track, then up a sloped concrete wall. She wants to reach a height of at least 10 feet above where she started before she turns to come back down the slope. She has measured her maximum running speed to safely jump on the skateboard at 7 feet/second. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned. She tells you that she weighs 100 lbs.

1.4 Rationale for Study

This study is the result of professors of the physics department at UW seeking to improve student learning and satisfaction of the Physics 103 course. Since the overarching goal of the class is to prepare students to be effective problem-solvers in their particular areas of study, it is beneficial to take advantage of work that physics education departments have already done and try them out in the UW classroom. Physics 103 is constrained to its present structure, student-to-professor and student-to-TA ratio, and allotted time, but it is both practical and feasible to make changes on the discussion level.

This study is being performed by a graduate student in the physics department with no formal education training. There are significant advantages to this, and as such many institutions have their own physics education research programs. Some of the advantages of this are as follows.

- Allows for "active research"

  In an active research environment, the researcher is the teacher and therefore has the combined goal of promoting and understanding the "process of change." "This paradigm, [rejects] the notion of researcher as disconnected observer…As applied to the study of education, the action research concept recognized the central role of the teacher as the primary agent of change in the classroom and the one best able to interpret the results."[5] While the researcher in this case is not the teacher, the researcher worked with the TAs and professor to implement these changes and has experience as a TA for physics104, the second semester of this introductory physics sequence.

- Results are expressed in language of its practitioners

One common problem with education research, particularly at the university level, is that there is little overlap between education research and university implementation. Having a graduate student in the department assessing the effectiveness of a class allows the method and results to be readily available and readable to professors within the department.

- Adaptability to unique environment

Changing the structure of an already implemented class is difficult. However, the introduction of new techniques and materials that interfere as little as possible with the current set-up is extremely valuable. Being a member of the department familiar with the course allows the researcher to write problems in such a way as to minimize extra time spent by the TAs and professor during the testing phase.

2. Research Approach and Equipment Design

The context rich problems used in this study are modifications of tools constructed by physics educations departments at other universities. According to the University of Illinois,

> …developing quality materials always requires a significant investment of both time and money. It is imperative that we combine our experiences and resources in this endeavor. Whenever possible, we have borrowed material directly from, or based our work on ideas from, the physics education community. In a similar spirit, we encourage others to take advantage of our experiences and materials and assimilate them into courses.[6]

It is in this spirit that this study relies on materials and research from other institutions.

2.1 Context rich problems

A set of discussion materials was previously put together by the instructor that included 3-4 textbook problems from the sixth edition *College Physics* by Serway and Faughn. Since the CR problems are more in-depth problems, it is reasonable to have the students work on only one problem during the 50 minute period. Therefore, to cut down on TA preparation time since TAs had students in both group A and group B, the context rich problems in this study were modified problems from the existing discussion materials. The problems were modified according to the University of Minnesota format by the researcher and are in Appendix C.

a. Administrative approach

The spring 2005, 103 Physics course was broken up into four sections.

- *Mechanics I*: motion in one and two dimensions, laws of motion, and energy (chapters 1-5)

- *Mechanics II*: momentum and collisions, rotational motion, gravity, rotational equilibrium and dynamics (chapters 6-8)
- *Thermodynamics* (chapters 9-12)
- *Vibrations and Waves* (chapters 13 & 14)

After each section there was a 20-question multiple choice exam testing conceptual and computational skills.

The class consists of two 50 minute lectures per week, two 50 minute discussions per week, and one two-hour lab each week. The discussion sections have around twenty students in them and are taught by a TA; the same TA teaches the lab and discussions for a given section.

In order to test the context rich question approach the discussion sections were divided semi-randomly into two groups, each TA had at least one section in each group. The sixteen groups were divided into two groups of eight as follows.

GROUP A
Vuosalo 601, 613
Kogut 603, 615
Brandl 605
Barnes 611
Trier 607
Lee 608

GROUP B
Vuosalo 602
Kogut 604
Brandl 612, 609
Barnes 606, 616
Trier 610
Lee 614

Each of the TAs was given a handout listing the instructions for the study implementation that briefly highlighted the differences between the CR and NCR methods as shown below.

> **Regular Method:** Continue with discussion formats used until now, 3-4 problems from the back of the book. Students work in groups and TAs help them.
>
> **New Method:** Used designed context rich problems; students only do 1 question per discussion.

The following implementation schedule was followed.

2/22 Midterm 1
3/3-3/17 **Group A** uses CR materials for five discussions
Group B uses only NCR materials
Spring Break
3/29 Midterm 2

3/31-4/22 **Group B** uses CR materials for five discussions
Group A uses only NCR materials
4/26 Midterm 3

b. Grading

Previously, in the NCR discussion, the TAs chose one problem of the 3-4 given to grade; grading is based primarily on participation. Once the sections were split into groups A and B, the TAs graded the CR problem for group A(B) and the related Serway problem for group B (A). This way the grading was not significantly altered by addition of the new discussion materials.

3. Data Analysis

The exams in Physics 103 are multiple-choice exams. They consist of twenty questions designed to test students' conceptual understanding. According to T. O'Brien, S. Vokos and L. C. McDermott,

> Tests that require only a short response (multiple-choice, true-false, etc.) can be administered to large populations in a relatively brief time period. The statistics obtained can give a general indication of student understanding of a range of topics and a rough measure of the prevalence of known student difficulties.[7]

This format not only gauges the students' understanding, but dramatically lessens the grading burden on the TAs, freeing them up for more contact hours with the students. This experiment takes advantage of the current test format to assess the effectiveness of using the CR problems in the discussion sections. It is worth noting however, that this type of exam only gives a "general indication of student understanding of a range of topics," therefore this is only used to obtain a general idea of how changing the discussion format while all other factors remained equal affects students general understanding.

4. Results

4.1 Type of discussion and midterm scores

Students' midterm grades were correlated with the type of discussion they participated in, CR or NCR. There were 165 students in group A and 152 students in group B. Students' midterm grades (out of a possible total of 100 points) and the standard deviations are given in table 1.

Group	Mean: midterm 1	Std dev 1	Mean: midterm 2	Std dev 2	Mean: midterm 3	Std dev 3
A	60.67	15.75	57.43	16.20	53.00	13.11
B	59.93	15.14	56.50	16.07	52.89	14.07

Table 1: Midterm grades

- At the time of **midterm 1** none of the groups had participated in CR discussions.
- At the time of **midterm 2** the students in group A had participated in five context rich discussions, and the students in group B had not participated in any context rich discussions.
- At the time of **midterm 3** the students in group A had been participating in NCR discussions since their previous five CR discussions, and the students in group B had participated in five CR discussion sections on the current material.

The null hypothesis was that there would be no effect between the midterm grades of the students who participated in CR discussions and NCR discussions. A two-tailed test was used to determine the p-values for the two groups for midterm 2 and midterm 3; it was found that the null hypothesis should not be rejected for either midterm 2 or midterm 3.

Midterm	t	P
2	0.513	>0.5
3	0.0723	>0.5

Table 2: P-values

4.2 Results by type of problem

Midterm 2 was coded by type of question, each question was designated as qualitative, computational, or mixed. Qualitative questions consisted of those with no numerical computations, computational had numerical computations required and numerical answers, and mixed questions required equation manipulation but not numerical solutions. The questions for each category are listed in Table 3 (see copy of midterm 2 in Appendix D). Also in Table 3 the average percentage of students in each group that answered each problem type correctly is listed.

Type of problem	Problem number	Average % correct: A	Average % correct: B
Qualitative	1, 2, 3, 4, 6, 8, 12, 17, 19	53.6	54.4
Computational	7, 12, 14, 15, 16, 18, 20	63.8	60.0
Mixed	5, 9, 10, 11	54.8	51.6

Table 3: Results after coding for problem type 2

After evaluation by a two-tailed test, no statistical difference between the average percentage of students in groups A and B that answered correctly was found for either the qualitative or computational questions.

5. Discussion of Results

The results of this study indicate that the type of discussion question did not have a **positive or negative** statistically significant effect on students' midterm scores, as anticipated by the claims of success from other departments. This could be due to a number of reasons, some of which are explored here.

5.1 The context rich problems used

The context rich problems in this study had to meet a number of criteria including, but not limited to, appropriate difficulty level, appropriate material, problems that mirrored the University of Minnesota, problems based on previously determined text-book problems, and problems that were written clearly. The majority of the problems were adapted from text-book problems to CR problems by the researcher following the guidelines from the U of MN.

The TAs were asked to evaluate these problems and it was suggested that some of the problems were too difficult for students to get through in the allotted time and some were not challenging enough to get at the real concepts. One reason that the CR discussions did not positively affect midterm grades could be that the CR problems used were not adequate to focus students on the problem-solving and other underlying skills they were meant to incorporate.

5.2 Lack of TA training

A related reason for this null result could be the lack of TA training. The University of Minnesota places great emphasis on training the TAs for their introductory level courses in administering CR problems. They have developed a TA instructor's guide for facilitating CR discussions and the TAs have many more hours of initial and continuing training than those at the University of Wisconsin. During meetings with the TAs throughout this study it was brought up that some of the problems could be easily solved if a hint was given, but the intention of the problem was to get students to figure out the "missing link" themselves. Training the TAs in giving effective hints and encouraging the students to think through the problems could engage the students more in the solving-by-thinking process, which is the goal of using CR problems in the first place.

5.3 Use of midterm grades for assessment

An additional reason for this result could be the effectiveness of using the midterm scores to evaluate student understanding. The midterms in this class are multiple choice questions and are, by design, meant to measure the students' conceptual knowledge of physics. The goals of using the CR problems and of the midterms are therefore slightly different. Students in CR discussions may have improved their problem solving skills, but may not have been able to translate that into the midterm format, thus their increased understanding may not have translated to a higher midterm score.

5.4 Additional factors

There are many other logistical and administrative differences between the discussions at U of WI and U of MN that may have contributed to this effect. These include seating arrangements during discussion, number of lectures and discussions per week, work load of TAs, etc. While it is not feasible to change the number of lectures per week for the introductory classes for example, from talking with the TAs and other research on physics education it seems that the logistical factors are not the dominant factor in student understanding.

5.5 Ineffectiveness of CR problems

The possibility that no effect was seen could also result from CR discussions not being a key to improving student understanding. One TA wrote on an end-of-the-semester evaluation, “I’m not sure that text-rich is the only answer, as I believe that many things could be changed…” In light of the results from other schools however, this first result is not sufficient for asserting this general result.

6. Suggestions for future research at the UW

This research has been an initial starting point for investing how discussion can be made more effective. The results raise a number of interesting questions that are worth looking into, in the light of the importance of physics education for students at the university level. Therefore, it would be beneficial to continue this research and look at the effects on student understanding when CR problems are incorporated with the increased TA training, further defined goals for physics 103, and a more continuous process of administration. One related area of interest would be to investigate how attitude and conceptual understanding are related, if CR problems do in fact lead to increased conceptual understanding.

6.1 Increase TA training

The TAs surveyed reported that increased training would be beneficial for administration of the CR problems. One TA wrote, “The TAs should be trained with the set of problems to be used during the semester. The answer key for each problem should explain the educational objectives of the problem. Training should address how to use the problems to help students gain the skills we are trying to teach.” This training needs to be in a way that does not increase the TA workload. One way to do this is to cut down on the individual preparation time of each TA and turn this allotted time into training/discussion on administering each specific problem. This training could fall under the job description of a hired graduate student as suggested in 6.1. The University of Minnesota has an extensive training program in place and many ideas can be gained from looking through their materials.

6.2 Further define goals of physics 103

Having a clearly laid out list of goals for physics 103 would allow an investigator to evaluate how different aspects of the course fit together to meet these goals, this is necessary to assess the effectiveness of the course and to provide explicit motivation for this type of research.

6.3 Continuous process of administration

In this study the students each participated in five CR discussions. A more thorough study would have students participating in the same type of discussion for the entire semester instead of changing half-way through. This may have thrown off the flow of the class as students are generally resistant to changes in class format once the semester is underway. This method would also be less complicated for the TAs and the researcher since there are fewer details of which to keep track.

6.4 Investigating the link between conceptual understanding and attitude

Finally, if a correlation between the context rich problem use and conceptual understanding is established, an interesting avenue of research would be to investigate whether the increased conceptual understanding does indeed correlate with improved attitude about the course, as claimed by the University of Colorado.[8]

7. Summary of conclusions

The value of a solid physics education is widely accepted by university professors, therefore increasing the effectiveness of the introductory physics classes should be a major concern for educational facilities. One of the aims of this study was to show the value and feasibility in inter-departmental education research even without a physics education group.

This study was a first effort at investigating improvements in the discussions for Physics 103, with further study these ideas can be refined and hopefully culminate in an improved 103 discussion that fits with the current logistics of the class. This could be done by supporting another graduate student with TA status to continue this work during the summer and regular semesters.

Although this study found no statistical improvements in the midterm scores of students using CR and those using NCR discussions, neither did it show any statistical declines in student scores. This, in addition to the fact that this method is widely endorsed by well-established physics education research groups, supports the fact that further research is needed to determine whether CR problems can be a logical way of increasing student understanding of introductory physics course material for the University of Wisconsin.

Appendix A

Creating Context Rich Problems[1]

One way to invent context rich problems is to start with a textbook exercise or problem, then modify the problem. You may find the following steps helpful:

0. Always start a context rich problem with "You." This personalizes and motivates the problem for the students.

1. If necessary, determine a context (real objects with real motions or interactions) for the textbook exercise or problem. You may want to use an unfamiliar context for a very difficult group problem.

2. Decide on a motivation -- Why would anyone want to calculate something in this context?

3. Determine if you need to change the target variable to
(a) make the problem more than a one-step exercise, or
(b) make the target variable fit your motivation.

4. Optional: Write the problem like a short story.

5. Decide how many "difficulty" characteristics (characteristics that make the problem more difficult) you want to include:
(a) determine extra information that someone in the situation would be likely to have
(b) leave out common-knowledge information (e.g., the boiling temperature of water);
(c) write the problem so the target variable is not explicitly stated;
(d) think of different information that could be given, so two approaches (e.g., kinematics and forces) would be needed to solve the problem instead of one approach (e.g., forces), or
(e) depending on the context, leave out explicitly giving some of the problem idealizations (e.g., massless rope).
6. Check the problem to make sure it is solvable, the physics is straight-forward, and the mathematics is reasonable.

BEWARE! Good group problems are difficult to construct because they can easily be made too complex and difficult to solve. A good group problem does not have all of the characteristics that make a problem more difficult, but usually only 3-4 of these characteristics.

Some common contexts include:

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[1] http://groups.physics.umn.edu/physed/Research/CRP/crcreate.html

- physical work (pushing, pulling, lifting objects vertically, horizontally, or up ramps)
- suspending objects, falling objects
- sports situations (falling, jumping, running, throwing, etc. while diving, bowling, playing golf, tennis, football, baseball, etc.)
- situations involving the motion of bicycles, cars, boats, trucks, planes, etc.
- astronomical situations (motion of satellites, planets)
- heating and cooling of objects (cooking, freezing, burning, etc.)

Sometimes it is difficult to think of a motivation. We have used the following motivations:

- You are . . . . (in some everyday situation) and need to figure out . . . .
- You are watching . . . . (an everyday situation) and wonder . . . .
- You are on vacation and observe/notice . . . . and wonder . . . .
- You are watching TV or reading an article about . . . . and wonder . . .
- Because of your knowledge of physics, your friend asks you to help him/her . . .
- You are writing a science-fiction or adventure story for your English class about . . . . and need to figure out . . . .
- Because of your interest in the environment and your knowledge of physics, you are a member of a Citizen's Committee (or Concern Group) investigating. .
- You have a summer job with a company that . . . . Because of your knowledge of physics, your boss asks you to . . . .
- You have been hired by a College research group that is investigating . . . . Your job is to determine . . . .
- You have been hired as a technical advisor for a TV (or movie) production to make sure the science is correct. In the script . . . ., but is this correct?
- When really desperate, you can use the motivation of an artist friend designing a kinetic sculpture!

Appendix B[2]

Rating the Difficulty of Context Rich Problems

Use the strategy below to decide whether you think each given context-rich problem is a good individual problem, group practice problem, or group test problem. Explain your reasoning for each decision.

1. Read the context rich problem statement. Draw the diagrams and determine the equations needed to solve the problem.

2. Reject if:

- the problem can be solved in one step,
- the problem involves long, tedious mathematics, but little physics; or
- the problem can only be solved easily using a "trick" or shortcut that only experts would be likely to know. (In other words, the problem should be a straight-forward application of fundamental principles.)

3. Check* for the eleven characteristics that make a problem more difficult:

1. unfamiliar context
2. hard to learn physics (e.g., circular motion, rolling friction, waves, Gauss's Law)
3. more than one approach is needed to solve the problem (e.g., force or kinematics)
4. more than two subparts are needed to solve the problem (e.g., two separate force diagrams then onto kinematics)
5. the target variable is not specified (i.e., more than one correct way to solve the problem)
6. more information is given than needed to solve the problem
7. needed information is missing
8. assumptions (idealizations) must be made to solve the problem
9. the solution involves vector components
10. finding the target variable requires trigonometric identities
11. the solution requires simultaneous equations or calculus (i.e., non-constant variables)

4. Decide if the problem would be a good (easy, medium, difficult) individual problem, group practice problem (20 - 25 minutes), or group test problem (45 - 50 minutes).

1. "Easy" individual problems usually have 0 - 1 of the characteristics that make a problem difficult. "Medium" difficulty individual problems have 1 - 3 of the difficulty characteristics, and "difficult" individual problems have 3 - 4 of these characteristics (excluding 1).

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[2] http://groups.physics.umn.edu/physed/Research/CRP/crjudge.html

2. Group practice problems should be somewhat shorter and mathematically easier than group test problems. That is, they usually have 2 - 4 difficulty characteristics, including some of the characteristics 2 - 7).
3. Group test problems can be more complex mathematically, and they usually have 3 - 5 of the difficulty characteristics.

As you become more sophisticated, you can give these difficulty characteristics weightings of 0, 1 and 2 instead of simple checks. For example, a problem that requires both the conservation of energy and momentum (weighting of 1) is easier than a problem that requires both circular motion and energy concepts (weighting of 2).

Appendix C

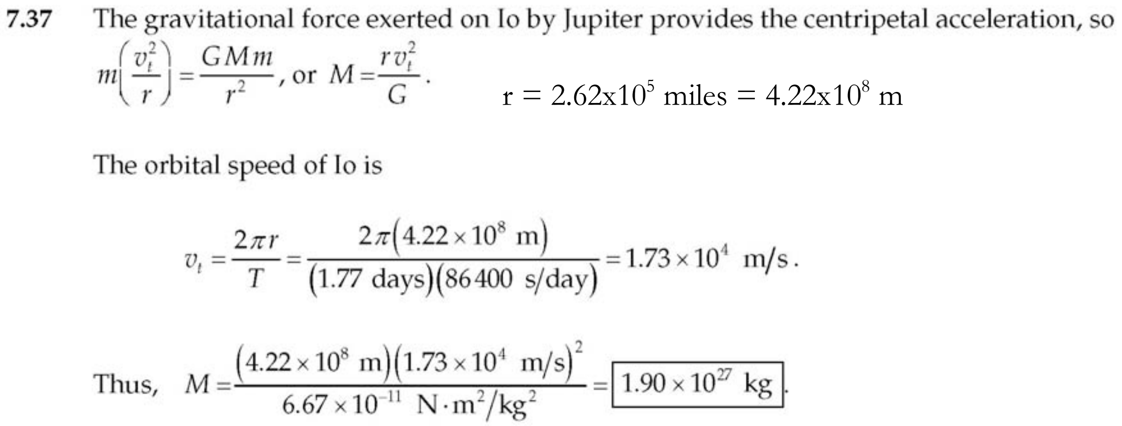
CR problems used in this study

Physics 103: Discussion 13-1

Colonizing Jupiter…

You are flying to Florida for spring break and end up sitting next to a funny old man on the plane. He notices you diligently studying for your upcoming physics exam and starts asking you whether we actually landed on the moon and whether you believe in string theory (he likes to watch TV specials). Anyway, he then tells you about a secret government program on colonizing Jupiter so that politicians and movie stars can go there when nuclear disaster strikes. He doesn't believe you when you tell him Jupiter is a gaseous planet made of mostly helium and hydrogen. You really want to get back to studying so you decide to prove to him that Jupiter cannot be Earth-like. The book you have with you says nothing about Jupiter except that it is the largest planet at a diameter of 88,673 miles. The book does, however, use Jupiter's moon Io in an example. The example lists Io's orbital period as 1.77 days, orbital radius as 2.62x10^5 miles, and distance from Jupiter as 2.2x10^5 miles. From this information prove that Jupiter is not dense enough to be another earth.

Find the mass of Jupiter as in problem 7.37. Then use the diameter and mass of Jupiter to find its average density (1.3 gm/cm^3*). Compare that to the average density of the Earth (5.5 gm/cm*^{3}*), the necessary info is in the back of their book.*



7.37 The gravitational force exerted on Io by Jupiter provides the centripetal acceleration, so

$$m\left(\frac{v_t^2}{r}\right)=\frac{GMm}{r^2}\text{, or } M=\frac{rv_t^2}{G}.$$

r = 2.62x10^5 miles = 4.22x10^8 m

The orbital speed of Io is

$$v_t=\frac{2\pi r}{T}=\frac{2\pi\left(4.22\times10^8\ \text{m}\right)}{\left(1.77\ \text{days}\right)\left(86400\ \text{s/day}\right)}=1.73\times10^4\ \text{m/s}.$$

$$\text{Thus, } M=\frac{\left(4.22\times10^8\ \text{m}\right)\left(1.73\times10^4\ \text{m/s}\right)^2}{6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2}=\boxed{1.90\times10^{27}\ \text{kg}}.$$

Jupiter:
M=1.9x10^{27} kg
D=88673 miles = 1.43x10^8 m
R=7.14x10^7 m

$$density=\frac{M}{V}=\frac{1.9x10^{27}kg}{\frac{4}{3}\pi(7.14x10^7m)^3}=1.5x10^3kg/m^3$$

Earth:
M=6x10^{24} kg
R=6.38x10^6 m

$$density=\frac{M}{V}=\frac{6x10^{24}kg}{\frac{4}{3}\pi(6.38x10^6m)^3}=5.5x10^3kg/m^3$$

Physics 103: Discussion 13-2

Space CowBoy

Lance Bass finally got his ride in a spacecraft. The craft is shaped like a long cylinder with a length of 100m, and a mass of 1000kg. Unfortunately the craft strayed too close to a 1.0m radius black hole that has a mass 100 times that of the sun. The nose of the spacecraft is pointing toward the center of the black hole and the distance between the nose and the black hole is 10.0km.

Before you do any calculations, what is a reasonable guess for the **total force on the spacecraft**?

a) 1 N
b) $1\text{x}10^{10}$ N
c) $1\text{x}10^{17}$ N

Now use Newton's third law to calculate the force.

7.54 (a) $F = \frac{GMm}{r^2}$

$$= \left(6.67\times10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}\right)\frac{\left[100\left(1.99\times10^{30}\ \text{kg}\right)\right]\left(1000\ \text{kg}\right)}{\left[10\times10^{3}\ \text{m}+50\ \text{m}\right]^2} = \boxed{1.3\times10^{17}\ \text{N}}.$$

What can you say about the **force on the black hole** from the spacecraft?

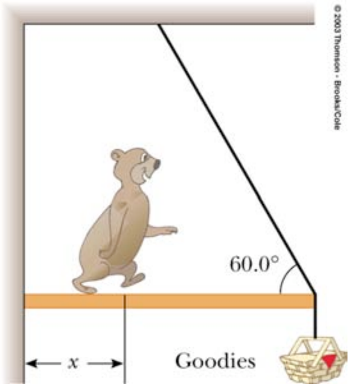
When one object applies a force on a second object, the second object applies a force on the first that has an equal magnitude but opposite direction.

Discussion 14

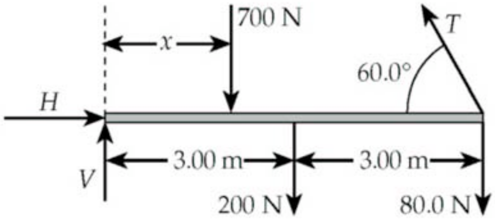
Walking the plank

You've been hired to work at a traveling circus for the summer. Recently promoted from shoveling manure, you're excited to try your hand at ordering products for new acts. The description of the first new act is as follows:

160 pound bear walks 6 m out on a 45 pound beam to get an 18 pound picnic basket. See design below:



a) As you look in the *Traveling Circus Parts* catalog, you realize that beam hinges are ordered based the maximum x and y reaction forces they need to exert and wires are ordered based on how much tension they need to withstand without breaking. You don't want to be responsible for a bear disaster, so you carefully figure out these quantities after drawing a free-body diagram for the beam. While you work, you use diagrams and/or words to justify each step so you'll be able to explain your decisions to your not-so-physics-savvy boss.



18 lbs = 8.2 kg
45 lbs = 20.4 kg
160 lbs = 72.6 kg

weight = mass * gravity
Basket: w=(8.2 kg)(9.8 m/s^2) = 80 N
Beam: w=(20.4 kg)(9.8 m/s^2)=200 N
Bear: w = (72.6 kg)(9.8 m/s^2) = 712 N

Maximum tension will be when the bear is at 6m:
Sum of tension: -(712 N)(6m)-(200N)(3m)-(80N)(6m)+(Tsin60)(6m)=0, T=1030 N.

Maximum reaction force in x will be when tension is greatest:
Sum of forces in x: h-Tcos60=0. h=(1030 N)cos60 = 515 N

Maximum vertical force on hinges will occur when the bear is standing at x=0.
This will have a minimum tension:
-(712 N)(0m)-(200N)(3m)-(80N)(6m)+(Tsin60)(6m)=0, so T=208N.

Therefore, sum of forces in y: v-(992 N)+(208N)sin60=0, v=812 N

b) You choose a wire with a tension of 1050 N. The circus also has a bear weighing 200 lbs. You wonder, how far out could this bear walk without breaking the wire?

-(889 N)x-(200N)(3m)-(80N)(6m)+(1050N)(sin60)(6m)=0, x=5m.

Discussion 15

A little too much merry-go-round

While sitting in Vilas Park one day you take a break from reading *Crime and Punishment* and watch some kids playing on the merry-go-round. The kids (Joe and Jane) are playing a game where Jane sits in the middle of the merry-go-round and Joe pushes it as fast as he can. They are laughing and having fun until Jane gets sick...Jane's mom runs up to the merry-go-round and stops it by pressing her hand along the outside edge. She pushes radially inward with a force of 50 N. This force acts as a normal force to create friction, therefore exerting a torque on the merry-go-round and slowing it down to a stop. **What was the angular velocity of the merry-go-round before Jane got sick?** Use the following estimates:

-A coefficient of friction equal to 0.5.
-It took about 3 s for Jane's mom to stop the merry-go-round
-The radius of the merry-go-round is 4 m
-The merry-go-round weighs 25 kg
-Jane weighs 30 kg

Fifteen minutes later you hear Jane begging to go on the merry-go-round again, but her mom is reluctant to let her. From your physics class you know that if Jane sits on the outside of the merry-go-round this time, even if Joe pushes as fast as he can, Jane won't rotate as fast. **What would Jane's angular velocity be if she sat on the outside at r = 4 m?**

Find the initial I

$$I_i = I_{Jane} + I_{Merry} = mr^2 + \frac{1}{2}MR^2 = \frac{1}{2}(25kg)(4m)^2 = 200kg \cdot m^2$$

Estimate initial speed of merry-go-round using *f*=50 N and t=3 s

$$\alpha = \frac{\omega_f - \omega_i}{\Delta t}, \omega_f = 0, \alpha = \frac{-\omega_i}{\Delta t}$$

$$\tau = -I\alpha = -I\left(\frac{\omega_i}{\Delta t}\right), \tau = -fr, \omega_i = \frac{\Delta t \cdot f \cdot r}{I}$$

$$\mu = \frac{f}{N}, f = \mu N = (0.5)(50N) = 25N$$

$$\frac{(3s)(25N)(4m)}{200kg \cdot m^2} = 1.5rad/s$$

Calculate the final angular momentum

$$\omega_f I_f = \omega_i I_i, \omega_f = \frac{\omega_i I_i}{I_f}$$

$$I_f = I_{Jane} + I_{Merry} = mr^2 + \frac{1}{2}MR^2 = (30kg)(4m)^2 + \frac{1}{2}(25kg)(4m)^2 = 680kg \cdot m^2$$

$$\omega_f = \frac{(1.5rad/s)(200kg \cdot m^2)}{680kg} = 0.44rad/s$$

(I would suggest doing 9.6 for the students first)

Discussion 16

Lifters R Us

Congratulations--you've just been hired as an intern for the innovative engineering company *Lifters* R *Us*. It's your job to write specifications for the latest development, the 3 speed Lifting Machine. The LM has the option of lifting objects upward with an acceleration of $1 m/s^2$, $2m/s^2$, or $3m/s^2$. The LM supports objects by attaching them to a steel cable 25 m long and $4.00 cm^2$ in cross-sectional area. The cable has an elastic limit of 2.2 x 108 Pa. Using this information, fill in the chart below and plot the results of each column as a function of acceleration.

Acceleration	Maximum mass cable can support at this acceleration	Elongation in cable at maximum mass
$0 m/s^2$	**8.90×10^3 kg**	**2.45×10^{-3} m**
$1 m/s^2$	**8.15×10^3 kg**	**2.70×10^{-3} m**
$2 m/s^2$	**7.46×10^3 kg**	**2.95×10^{-3} m**
$3 m/s^2$	**6.88×10^3 kg**	**3.20×10^{-3} m**

From these trends, how could you increase the maximum mass the cable can support?
Decrease acceleration

How could you increase the elongation of the cable?
Increase acceleration

If you wanted to increase the elongation without changing the acceleration, would you increase or decrease the mass?
Increase

What property of the cable would you change to increase the maximum mass?
Increase cross-sectional area

To increase the elongation?
Increase the length

To find maximum mass:

$$stress = F / A, F_{\max} = A(stress)_{\max} = (4x10^{-4} m^2)(2.2x10^8 Pa) = 8.8x10^4 N$$

$$F_{\max \cdot tension} - mg = m \cdot a_y, m_{\max} = \frac{F_{\max}}{g + a}$$

To find elongation:

$$Y = \frac{F \cdot L_o}{A \cdot (\Delta L)}, \Delta L = \frac{m(g + a) \cdot L_o}{A \cdot Y}$$

Discussion 17

THIRTEEN IS THE NEW TWELVE

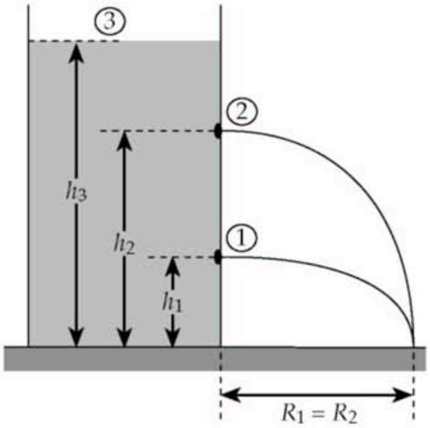
Because of your knowledge of physics, and because your best friend is the third cousin of the director, you have been hired as an assistant to the assistant technical advisor of Ocean's 13—being shot on location in Wisconsin. In one scene the writers have George Clooney loading gold bricks onto a ferry boat 4 m wide and 6 m long. There are supposed to be 1000 gold bars on the cart, each weighing 1,000 g. The director wants this scene to be realistic, so how much should this gold cause the ferry to sink?

The boat sinks until the weight of the additional water displaced equals the weight of the gold:

$$W_{gold} = [\rho_{water}(\Delta V)]g => (1000kg)(g) = \left(10^3 kg/m^3\right)(4m)(6m)d](g)$$

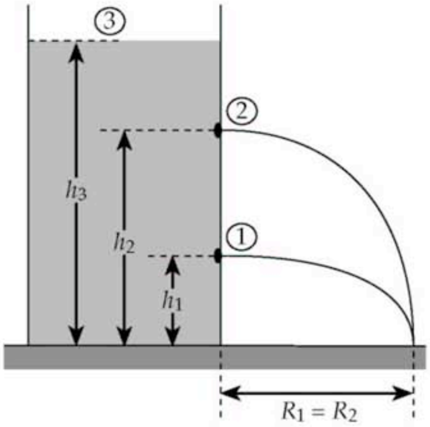
$$d = 4.12cm$$

In the next scene Brad Pitt is immersed in a clear tank of water that is open to the atmosphere on top. He punches two small holes in the side with his pocket knife before breaking it, one at h_1=5 ft and one directly above it at h_2=12 ft. The director wants a shot as shown in the picture, with the two streams of water hitting the floor at the same place. How high should the water be in the tank (h_3)? It's a big tank so you can ignore the displacement from Brad Pitt. Begin by assuming a water droplet emerges from one of the holes as a projectile, then use kinematics and Bernoulli's equation to find the height of the water.



Same as in 9.87 but in ft instead of cm.

9.87 A water droplet emerging from one of the holes becomes a projectile with $v_{iy} = 0$ and $v_{ix} = v$. The time for this droplet to fall distance h to the floor is found from $\Delta y = v_{iy}t + \frac{1}{2}a_y t^2$ to be $t = \sqrt{\frac{2h}{g}}$.



The horizontal range is $R = vt = v\sqrt{\frac{2h}{g}}$.

If the two streams hit the floor at the same spot, it is necessary that $R_1 = R_2$, or

$$v_1\sqrt{\frac{2h_1}{g}} = v_2\sqrt{\frac{2h_2}{g}}$$

With $h_1 = 5.00\text{ cm}$ and $h_2 = 12.0\text{ cm}$, this reduces to

$$v_1 = v_2\sqrt{\frac{h_2}{h_1}} = v_2\sqrt{\frac{12.0\text{ cm}}{5.00\text{ cm}}}\text{, or } v_1 = v_2\sqrt{2.40} \tag{1}$$

Apply Bernoulli's equation to points 1 (the lower hole) and 3 (the surface of the water). The pressure is atmospheric pressure at both points and, if the tank is large in comparison to the size of the holes, $v_3 \approx 0$. Thus, we obtain

$$P_{atm} + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_{atm} + 0 + \rho g h_3\text{, or } v_1^2 = 2g(h_3 - h_1). \tag{2}$$

Similarly, applying Bernoulli's equation to point 2 (the upper hole) and point 3 gives

$$P_{atm} + \frac{1}{2}\rho v_2^2 + \rho g h_2 = P_{atm} + 0 + \rho g h_3\text{, or } v_2^2 = 2g(h_3 - h_2). \tag{3}$$

Square equation (1) and substitute from equations (2) and (3) to obtain

$$2g(h_3 - h_1) = 2.40\left[2g(h_3 - h_2)\right]$$

Solving for h_3 yields

$$h_3 = \frac{2.40h_2 - h_1}{1.40} = \frac{2.40(12.0\text{ cm}) - 5.00\text{ cm}}{1.40} = 17.0\text{ cm},$$

so the surface of the water in the tank is $\boxed{\text{17.0 cm above floor level}}$.

Discussion 19

Walking on Air

In a weak moment you volunteered to take care of the decorations for your little brother's prom. The theme for the prom is "Walking on Air." The prom committee decided they want the entire ceiling of the dance floor lined with helium balloons—this is the part that falls under your control. After a little research you find out that you can order tanks of helium in volume increments of 0.01 m^3 and they come standard at 150 atm. The ceiling is 5 m high; the floor is 10 m wide by 10 m long. You also determined that the average balloon has a diameter = 0.30 m at a pressure of 1.20 atm, what volume helium tank should you order?

The area of the ceiling is $(10m)(10m) = 100m^2$

So, the number of balloons that will fit is approximately $\frac{100m^2}{\pi r^2} = \frac{100m^2}{\pi(0.15m)^2} = 1414$

The volume of helium in each balloon is $v = \frac{4}{3}\pi r^3$ so the total volume of helium needed is $1414 * v = (1414)\frac{4}{3}\pi(0.15m)^3 = 20m^3$, use this to find the needed volume of tank:

$$v_{\tan k} p_{\tan k} = v_{balloon} p_{balloon}, v_{\tan k} = \frac{v_b p_b}{p_t} = \frac{20m^3 * 1.20atm}{150atm} = 0.16m^3.$$

After you finish filling all of the balloons someone decides to cool down the area, so he opens the windows. Doing this lowers the temperature in the room by 5 degrees Celsius. When the committee walks in they are disgusted with you for not filling up the entire area with balloons. Show how the change in temperature affected the volume filled by the balloons.

$$\Delta v = \beta v_o \Delta T$$

$$\beta_{helium} = 3.665x10^{-3}[(°C)^{-1}]$$

$$\Delta v = (3.665x10^{-3}[(°C)^{-1}])(20m^3)(5°C) = 0.3665m^3$$

Discussion 20

Don’t hold your breath…

While looking over a list of classes offered this summer, you notice a scuba diving course. This sparks a discussion between you and Sally (a friend who took the class last summer). Sally says that the one thing she remembers from the class is to never hold her breath while scuba diving. You grew up free diving into lakes and pools and are surprised by this because you always hold your breath when you dive. Sally’s response is, “Well, it has something to do with the fact that scuba divers breathe through a regulator that keeps the air at a constant pressure…”

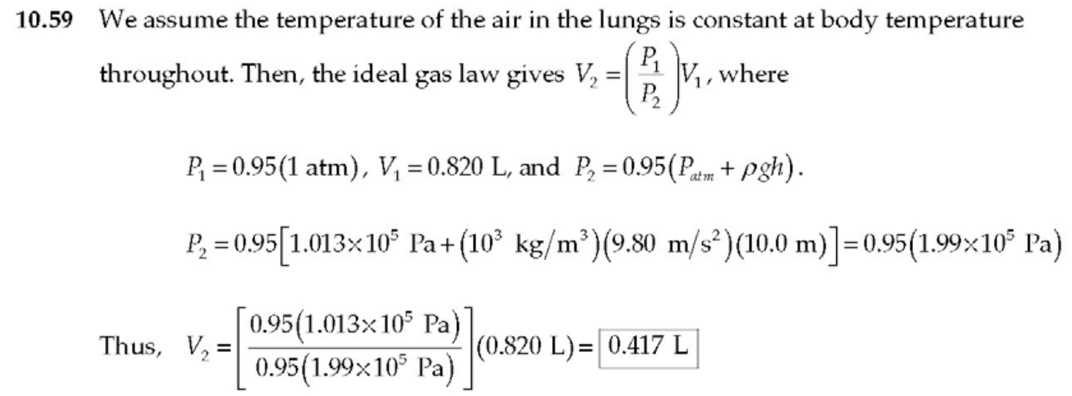
Explain conceptually the difference between why free divers can hold their breath and scuba divers should not.

When you take a full breath and dive underwater (free dive), the air inside your lungs compresses as you go deeper. As you come up, that same air expands proportionally. By the time you reach the surface, the air in your lungs is back to the volume you started with, assuming you held your breath the entire time and didn't let any air escape.

While scuba diving, you breathe from the regulator, so your lungs are constantly refilled with ambient-pressure air. When you decide to surface, you are starting the ascent with your lungs already expanded as opposed to compressed like a free diver's. If you hold your breath this air will expand even more as you rise…
(http://www.scubabyte.com/scubadivingsafety.htm)

Evaluate the following situations:

You free dive into a lake with 0.820 L of dry air in your lungs. Assuming that the pressure of dry air = 95% of external pressure at all times, what is the volume of dry air in your lungs at a depth of 10.0 m?



10.59 We assume the temperature of the air in the lungs is constant at body temperature throughout. Then, the ideal gas law gives $V_2 = \left(\frac{P_1}{P_2}\right)V_1$, where

$$P_1 = 0.95(1\ \text{atm}),\ V_1 = 0.820\ \text{L, and}\ P_2 = 0.95(P_{atm} + \rho g h).$$

$$P_2 = 0.95\left[1.013\times10^5\ \text{Pa} + \left(10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)(10.0\ \text{m})\right] = 0.95\left(1.99\times10^5\ \text{Pa}\right)$$

$$\text{Thus,}\quad V_2 = \left[\frac{0.95\left(1.013\times10^5\ \text{Pa}\right)}{0.95\left(1.99\times10^5\ \text{Pa}\right)}\right](0.820\ \text{L}) = \boxed{0.417\ \text{L}}$$

Sally scuba dives to a depth of 10.0 m, what is the volume of dry air in her lungs if she also starts with 0.820 L of dry air in her lungs?

The volume in her lungs will be the same as when she started.

Discussion 21

CSI Madison

Due to the success of CSI, CSI Miami, and CSI NY, CBS has decided to add CSI Madison to the Tuesday night lineup. In the pilot episode a former UW Professor known to be working on a top secret project is found murdered. The cause of death is a 3.00-g lead bullet. The body was found in a freezer, behind a large block of ice. The killer fired his first shot at the professor through the block of ice, but the bullet was embedded in the ice and didn't pass through. Learning from his miscalculation, the killer fired his second and final shot from below the block. The block was at 0°C and sat on a shelf 0.5-m off of the ground. The CSI team noticed a patch of ice below the block that must have formed after the first shot caused 0.294-g of ice to melt. Assuming the shooter held his gun up to the block of ice when he fired, at what speed did the bullet leave the gun (assume it left at 30°C)?

Because the large block of ice will not all melt, the bullet must give up its original kinetic energy and also cool to 0°C.

Conservation of energy equation: $m_{melt}L_f = \frac{1}{2}m_b v_i^2 + m_b c_{Pb}(\Delta T)$

$$v_i = \sqrt{2\left(\frac{m_{melt}L_f}{m_b}\right) - c_{Pb}(\Delta T)} \qquad v_i = \sqrt{2\left(\frac{(0.294g)(3.33x10^5)}{3g}\right) - (128J/kg)(30^o C)}$$

The murder was very careful not to get locked into the freezer—not only because it was 0°C, but because his presence would warm the freezer up a detectable amount. Assume the man had a power output of about 200 W and that the freezer dimensions were 6.0-m by 3.0-m by 3.0-m. What would the temperature of the room be at the end of 1.0-h if all the energy remained in the air in the room and none was added by an outside source (neglect the deceased professor)?

The energy added to the air in one hour is:

$Q = (P_{total})t = (200w)(3600s) = 7.2x10^5 J$

and the mass of the air in the room is:

$m = \rho v = (1.3kg/m^3)[(6.0m)(3.0m)(3.0M)] = 70.2kg$

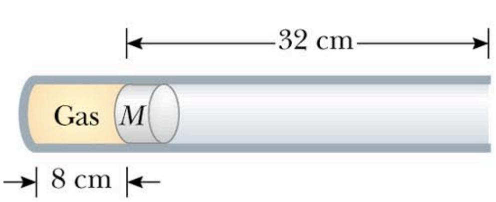
The change in temperature is

$$\Delta T = \frac{Q}{mc} = \frac{7.2x10^5 J}{(70.2kg)(837J/kg \circ C)} = 12.3 \circ C$$

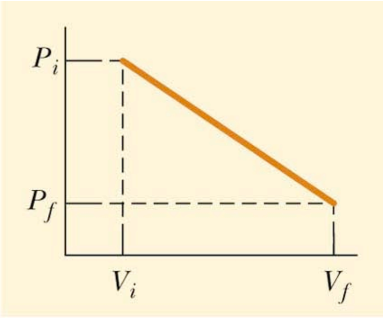
giving $T_f = T_i + \Delta T = 0 \circ C + 12.3 \circ C = 12.3 \circ C$

Discussion 22

You are helping your little sister with her science fair project on gas expansion. She has decided to illustrate expansion by launching a projectile in an arrangement shown in the picture below. The launch tube has a cross-sectional area of 1.0 cm^2, and the projectile travels 32 cm down the launch tube after starting from rest. As the gas expands, the pressure varies as shown in the graph. The values for the initial pressure and volume are $P_i = 11 \times 10^5$ Pa and $V_i = 8.0$ cm^3, and the final values are $P_f = 1.0 \times 10^5$ Pa and $V_f = 40.0$ cm^3. Your sister wants to make sure the projectile comes out at a speed of at least 30 m/s, what mass projectile should she use?



(a)



(b)

The work done *by* the gas on the projectile is given by the area under the curve in the *PV* diagram. This is

$$
\begin{aligned}
W_{\text{by gas}} &= (\text{triangular area}) + (\text{rectangular area}) \\
&= \frac{1}{2}(P_0 - P_f)(V_f - V_0) + P_f(V_f - V_0) = \frac{1}{2}(P_0 + P_f)(V_f - V_0) \\
&= \frac{1}{2}\left[(11 + 1.0) \times 10^5 \text{ Pa}\right]\left[(40.0 - 8.0) \text{ cm}^3\right]\left(\frac{1 \text{ m}^3}{10^6 \text{ cm}^3}\right) = 19 \text{ J}
\end{aligned}
$$

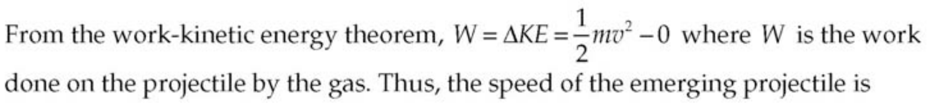
The air in front of the projectile would exert a retarding force of

$$F_r = P_{air}A = (1.0 \times 10^5 \text{ Pa})\left[(1.0 \text{ cm}^2)(1 \text{ m}^2/10^4 \text{ cm}^2)\right] = 10 \text{ N}$$

on the projectile as it moves down the launch tube. The energy spent overcoming this retarding force would be

$$W_{spent} = F_r \cdot s = (10 \text{ N})(0.32 \text{ m}) = 3.2 \text{ J},$$

So the total work is $W_{by-gas} - W_{spent} = 19J - 3.2J = 15.7J$



From the work-kinetic energy theorem, $W = \Delta KE = \frac{1}{2}mv^2 - 0$ where W is the work done on the projectile by the gas. Thus, the speed of the emerging projectile is

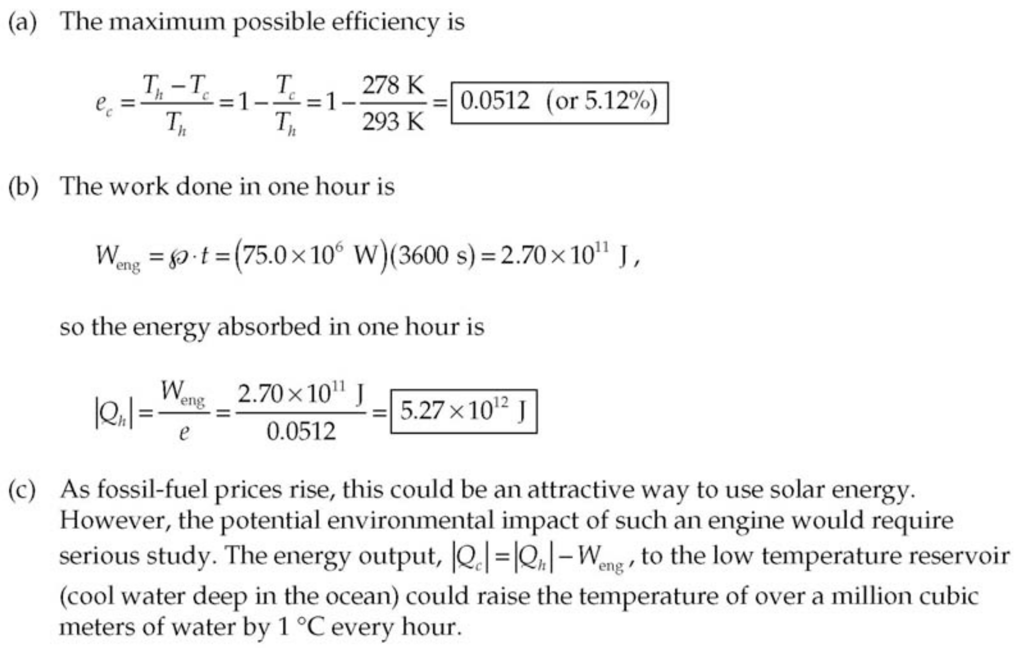
$$m = \frac{2(W_{net})}{v^2} = \frac{2(15.7J)}{(30m/s)^2} = 34.8g$$

I included one problem exactly from the discussion at the begging of this question, since many said the discussion questions are not always long enough. You can go through them as a class or have the students work on them together. The purpose of the CRP, the second problem, is for them to figure out what conceptual connections to make so let them struggle with this for a while is they need to.

Discussion 23

Here a fish there a fish...

1. A power plant has been proposed that would make use of the temperature gradient in the ocean. The system is to operate between 20.0°C (surface-water temperature) and 5.00°C (water temperature at a depth of about 1 km). (a) What is the maximum efficiency of such a system? (b) If the useful power output of the plant is 75.0 MW, how much energy is absorbed per hour? (c) In view of your answer to (a), do you think such a system is worthwhile (considering that there is no charge for fuel)?



(a) The maximum possible efficiency is

$$e_c = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h} = 1 - \frac{278\ \text{K}}{293\ \text{K}} = \boxed{0.0512\ \ (\text{or } 5.12\%)}$$

(b) The work done in one hour is

$$W_{\text{eng}} = \wp \cdot t = (75.0 \times 10^6\ \text{W})(3600\ \text{s}) = 2.70 \times 10^{11}\ \text{J},$$

so the energy absorbed in one hour is

$$|Q_h| = \frac{W_{\text{eng}}}{e} = \frac{2.70 \times 10^{11}\ \text{J}}{0.0512} = \boxed{5.27 \times 10^{12}\ \text{J}}$$

(c) As fossil-fuel prices rise, this could be an attractive way to use solar energy. However, the potential environmental impact of such an engine would require serious study. The energy output, $|Q_c| = |Q_h| - W_{\text{eng}}$, to the low temperature reservoir (cool water deep in the ocean) could raise the temperature of over a million cubic meters of water by 1 °C every hour.

2. The new proposal for building a nuclear power plant on the outskirts of your hometown along the Hometown River has many in a tizzy. People are opposing this for different reasons—economic, lack of attractiveness, danger of radiation, etc. But, being a fish lover, your main concern is damage to the fish because of the energy exhausted by the power plant. You have access to the proposal which gives the input power to the boiler in the plant as 25 x 10^8 W, the useful power output of the plant as 2,000 MW, and the efficiency of the use of this power as roughly 6 times that proposed as for the ocean-based plant. Thanks to the internet you find the river flow rate to be 9.0 x 10^6 kg/min. Would this disrupt the local fish population is they are sensitive to temperature changes of 3 degrees Celsius or more?

The energy output to the river each minute has magnitude

$$|Q_c| = (1-e)|Q_h| = (1-e)\left(\frac{|Q_h|}{t}\right)\cdot t = (1-0.30)\left(25\times10^8\ \frac{\text{J}}{\text{s}}\right)(60\ \text{s}) = 1.05\times10^{11}\ \text{J}$$

so the rise in temperature of the $9.0\times10^6\ \text{kg}$ of cooling water used in one minute is

$$\Delta T = \frac{|Q_c|}{mc} = \frac{1.05\times10^{11}\ \text{J}}{\left(9.0\times10^6\ \text{kg}\right)\left(4186\ \text{J/kg}\cdot{}^\circ\text{C}\right)} = \boxed{2.8^\circ\text{C}}$$

Appendix D

Physics 103 midterm 2

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[1] L. C. McDermott, “How we teach and how students learn – A mismatch?,” Am. J. Phys. 61, (1993).

[2] The National Academies. National Science Education Standards. (1995) http://www.nap.edu/readingroom/books/nses/html/overview.html

[3] University of Minnesota PER group. Context Rich Problems. http://groups.physics.umn.edu/physed/Research/CRP/crintro.html

[4] University of Minnesota PER group. Context rich problems compared to Traditional Problems. http://groups.physics.umn.edu/physed/Research/CRP/crcompare.html

[5] J. P. Adams and T. F. Slater, “Using Action Research to Bring the Large Class Down to Size,” Journal of College Science Teaching 28, 87-90 (1998).

[6] T. Stelzer and G. Gladding, “The Evolution of Web-Based Activities in Physics at Illinois,” Forum on Education Fall 2001 Newsletter (2001).

[7] T. O’Brien, S. Vokos and L. C. McDermott, “The challenge of matching learning assessments to teaching goals: An example from the work-energy and impulse-momentum theorems,” Am. J. Phys. 66 (2), (1998).

[8] K. K. Perkins, W. K. Adams, S. J. Pollock, N. D. Finkelstein and C. E. Wieman, “Correlating Students Attitudes With Student Learning Using The Colorado Learning Attitudes about Science Survey.”