Body Physics

Motion to Metabolism

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Lawrence Davis

OpenOregon
Educational Resources

BODY PHYSICS: MOTION TO METABOLISM

LAWRENCE DAVIS

DEDICATION

For my wife Liz, who continuously teaches by example how to be a great teacher, parent, friend, spouse and human being.

For my children, who continuously teach me perspective and show me how to find wonder in the everyday world.

And for all those great teachers who have dedicated themselves to enriching the lives of students.

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WHY USE BODY PHYSICS?

It's Free! And Open! And Accessible!

It's definitely not perfect, but you can make it better!

Body Physics is an open education resource (OER) licensed under the creative commons (CC) format with support from OpenOregon.

Join the Open Educational Resource movement and save your students money while providing them with high quality, accessible resources in digital and print formats, all while gaining greater control over your own course resources.

The *Body Physics* format and features were designed with the following considerations in mind, in arbitrary order:

Digital, free and open	Creative commons (CC) license. Digital formats (PDF, ebook, Web Viewing) free to students. Free printable lab sheets included, no separate lab manual to buy.
Low printing cost	No superfluous (curb appeal) images, clean margins. Links to large tables and charts of constants and other data.
Accessible, streamlined, not distracting	In-line diagrams and images containing alternative text, no side-bars or use of margins, basic and consistent heading structure, descriptive links.

Pedagogically sound	Backwards design: Unit outcomes aligned with course outcomes, content and exercises aligned with chapter outcomes. Links to additional resources (articles, texts, simulations, videos, problems with solutions). In-line reinforcement activities provide immediate feedback. Many every-day examples and applications. Structured inquiry-based labs designed to reinforce chapter content and assess learner outcomes. Suggested Personal response system (PRS) questions provided.
Interesting and engaging to students with varied interests	All content is introduced in the context of the human body, then abstracted, generalized, and applied to additional applications.

DESIGN THEORY

With a wealth of information available, introductory textbooks no longer need to serve as sole sources for all course content. However, now possibly more than ever, textbooks may still have an important role in providing students with high quality ***context*** for all of the information floating around out there. Textbooks should also serve as a central hub connecting students to other high quality resources vetted by experts. Finally, textbooks should help students to connect concepts to their own experiences to improve and lengthen understanding. *Body Physics* was created with these roles in mind.

Body Physics sticks to the basic functioning of the human body, from motion to metabolism, as a common theme through which the fundamental physics topics are introduced. This choice allows for a contextual format and narrative quality that connects concepts in different sections and chapters. The common narrative thread does not necessarily prevent individual chapters, sections, or activities from being used as stand-alone content. For example the ***Jolene's Migraines*** example and reinforcement activity could be useful in any science class covering the scientific method. The human body was chosen as the contextual theme so that all students are able to connect with the theme a personal way. For students who are athletes, entering health fields, interested in fitness, struggle with unique physical barriers, or are simply curious about their body, the book should feel particularly applicable.

While many of the existing OER resources are of very high quality, and would be very useful for a variety of courses, most are typically written from the point of view of someone who already possesses a great appreciation for physics. In general terms they are approached with hindsight not held by the student. Even if unconsciously, presentation of content is often driven by appreciation for the elegant universality of fundamental physics concepts, with the goal of bringing similar appreciation to the student. Often the results are general physics concepts presented in an abstract way and then connected to every-day life through examples and application problems. For example, a chapter might be called *Forces and Newton's Laws of Motion,* with sections called *Forces, Newton's First Law, Newton's Second Law, Newton's Third Law*. Of course applications would be provided throughout the sections and the end of the chapter would have likely an *Applications of Newton's Laws* section addressing applications in several different areas of interest, possibly including the human body.

Body Physics attempts to invert the content presentation sequence where logical and integrates the initial presentation of content into a common application theme. For example, the concept of a force is introduced in the Unit titled *Better Body Composition Measurement* using two forces the students have experienced and heard of, namely weight and buoyant force. The unit jumps right into applying these concepts to solving a real-world problem, namely determining body density, and the concepts necessary to solve the problem, such as static equilibrium, are introduced as needed along the way. Generalization of concepts occurs at then end of the unit, or even in a later unit, after concepts have become more familiar and connections between concepts have been discovered. This departure from the standard, highly structured textbook format is only made possible by the quickly searchable nature of digital textbooks such as this one, which allow students to quickly and easily find concepts and definitions embedded in a contextual, even narrative format. As a physicist, and someone who learned from standard textbooks, this departure was not easy. As I worked on an outline for the book, found myself unconsciously falling back into the standard organizational structure (and the one in my own head), before "waking-up" and going back to attempt a reorganization of the material from the point of view of a brand new science student.

HOPE AND HYPOTHESIS

It's exceedingly rare that science textbooks are read word-for-word, and this book won't change that, especially as the number of auxiliary resources available to students grows. However, we do hope that *Body Physics* will increase the amount of time students spend using the textbook to learn and prepare in a pedagogically sound manner. There is no guarantee that the format of body physics will be effective than standard formats and only after observing student performance and receiving feedback from students and instructors will we know if this endeavor was fruitful. Ideally we would like to test the hypothesis: *If the* Body Physics *format is more effective than standard formats, then students using* Body Physics *will perform at a higher level on assessments of learner outcomes than peer students using a standard textbook*. If you would like to collaborate in performing a statistically robust test of such a hypothesis, please contact bodyphysicstext@gmail.com

WHEN TO USE BODY PHYSICS

Body Physics was designed to meet the objectives of a one-term high school or freshman level course in physical science, typically designed to provide non-science majors and undeclared students with exposure to the most basic principles in physics while fulfilling a science-with-lab core requirement. The content level is aimed at students taking their first college science course, whether or not they are planning to major in science. However, with minor supplementation by other resources, such as OpenStax College Physics, this textbook could easily be used as the primary resource in 200-level introductory courses. Chapters that may be more appropriate for physics courses than for general science courses are noted with an asterisk symbol (*). Of course this textbook could be used to supplement other primary resources in any physics course covering mechanics and thermodynamics. The following are an example course description and course outcomes (learner outcomes, learning objectives, etc.) for which Body Physics would be well aligned (see unit outcomes for alignment to course outcomes indicated by [#]):

Elementary concepts of physics including motion, forces, energy and momentum, and thermodynamics. Registration-Enforced Prerequisite MTH 060. 3 lecture, 3 lab hrs/wk.

1. Apply knowledge of the SI units, metric prefixes, and unit conversion factors in solving physics problems.
2. Analyze, rank, compare, and make predictions about qualitative physics scenarios involving motion, forces, energy, momentum and thermodynamics.
3. Analyze and solve quantitative physics problems involving motion, forces, energy, momentum and thermodynamics.
4. Demonstrate proficiency with laboratory equipment, computer software, and experimental procedures for gathering, recording, analyzing and graphing data.
5. Apply the basic scientific method.

HOW TO USE BODY PHYSICS

THE ADOPTION PROCESS

Adopt the entire book or simply use certain content or features to supplement your course materials. If you decide to adopt the book as a required text for your course, consider the following:

- Give plenty of advanced notice to your bookstore to prevent sticking them with expensive unused inventory.
- Work with your bookstore and independent/non-profit printers like Montezuma to provide low-cost print copies for students.
- Check that the textbook content aligns with the course outcomes for your course. The example course outcomes and the Learner Outcomes for each chapter should help with this check.
- Work with your library to get print copies on reserve.
- Provide a link to the book on your LMS. You might consider linking each assigned reading directly to that Unit in the book.
- Ask for feedback from students and record your own

feedback to pass on to the author and help to improve the textbook. Send feedback to bodyphysicstext@gmail.com

BEST USE OF SPECIAL DESIGN FEATURES

Learner Outcomes

- The learner outcomes listed at the beginning and end of each unit provide instructor and student with an overview of what topics will be covered.
- They help the instructor to find section of the book that are applicable their specific course.
- They may help instructors design assessment methods that are specific and relevant while ensuring that course activities are outcome related.
- To aid instructors with adoption, the alignment of the learner outcomes for each unit with the example overall course outcomes is indicated by the number in [brackets] following each outcome.

Everyday Examples

- Everyday examples provide additional context to help students relate to new concepts; some are conceptual and some provide worked examples with answers.
- Everyday examples often make excellent topics for

discussion in class or online and can be used to inspire reading quiz questions.

Reinforcement Activities

- Reinforcement Activities provide students with immediate practice on difficult concepts.
- Some Reinforcement Activities are tactile, some are qualitative questions, and some are quantitative.
- The reinforcement activities could be assigned in the place of traditional "homework" and some class time (1-2 hrs/week) could be used for students to work on the end-of-unit Practice and Assessment problems in groups with instructor help. This hybrid-flipped classroom approach might time students spend interacting with the textbook outside of class and is especially useful for courses with under-prepared students.
- Reinforcement activities can be integrated into interactive lectures.

Key Terms and Concepts

- The list of key terms and concepts found at the end of each unit can help students to review what they have learned and check their comprehension.

- The list may also help instructors decide which units of the book are applicable to their specific course.
- The list of key terms and concepts is useful to instructors in designing discussion topics, study guides, weekly quiz questions, and conceptual exam questions.
- We hope to eventually have key terms and concepts linked to explanations from external sources, encompassing a variety of media types.

Additional Features

- **Global glossary** allows for quick reference to definitions of key terms and concepts
- **Practice and Assessment Exercises** provide students with practice and instructors with an assessment tool. These problems could be assigned as standard homework problems or group problems in a "flipped classroom" or tutorial session.
- **Conceptual Questions** (coming soon) organized by unit are excellent for use as personal response system (clicker) questions to create interactive lectures or games for review. They might also be used as quiz or multiple choice exam questions.
- **Design-Build-Test** projects allows students to incorporate their own experience and knowledge into creation of a model system based on the concepts covered in the book.
- **Complete Lab** activities are designed to familiarize students with the scientific method and are aligned with learner outcomes. They are located together in a single unit for easy printing. You may want to consider working with your bookstore to provide a printed Lab Manual. After adapting and improving the labs, please share your

improved versions with the OER community. You can always e-mail feedback and suggested improvements to bodyphysicstext@gmail.com

- **In-text links to videos** (more soon) from open sources such as Khan Academy provide supplementary explanation to help students with concepts in the moment or during review.
- **Links to simulations** from open sources such as Phet provide interactive experience with concepts in the moment or during review.

TASKS REMAINING AND COMING IMPROVEMENTS

COMING IMPROVEMENTS

Body Physics will be subjected to a continuous improvement process. If you would like to contribute content, feedback, edits, or if you have any questions about Body Physics, please e-mail: bodyphysicstext@gmail.com.

The following is a list of improvements we hope to implement over the long term. There will likely be changes to this list as we learn from using the book and receive feedback from others.

1. ~~Creating a global glossary and adding “rollover” action to glossary term~~
2. H5P integration for reinforcement exercises?
3. Reordering of chapters to focus locomotion and energy and improve flow (2nd ed?)
4. Shifting of some non-100 level content and activities to the Body Physics Supplement
5. A mind-map or correspondence table showing how sections relate to topics (sections in a standard book)
6. Adding and improving reinforcement activities, everyday examples, and practice exercises

7. Internal Linking
8. Solutions to Reinforcement Activities
9. Solutions to Practice and Assessment Exercises
10. Compiling a conceptual question bank
11. Tabulate links to vetted external resources (text and video) for all key terms and concepts
12. Improving lab activities and adding student-contributed images and videos
13. Chapter specific video lectures w/ demonstrations
14. Concept specific Algodoo simulations and activities

WHO CREATED BODY PHYSICS?

The following people were instrumental in the creation of Body Physics as an Open Education Resource. Body Physics would not have been created without their efforts. Sole responsibility for errors, including but not limited to, grammatical, typographical, technical, attribution, format, and export errors, lies with the author.

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Dr. Lawrence (Mick) Davis is an Associate Professor of Science at Umpqua Community College (UCC) in Roseburg, OR where he teaches General Physical Science, General Physics, General Physics with Calculus, and Water Resource Science. In his spare time Mick enjoys alpine climbing, volunteering with Eugene Mountain Rescue, working with UCC's wrestling teams (men and women), participating in outreach activities such as STEAMHub, and now writing OER textbooks. Mick's interests in STEM education and in body physics were both sparked by his time at Pacific University where he earned a B.S. in Physics and a top-10 national ranking in wrestling. Mick's body physics interest continued through graduate school at the University of

Oregon (UO) where he earned a Ph.D. in physics and traded wrestling for climbing as an excuse to get out of the lab. Mick's research focused on the growth, morphology, and optical properties of metallic nanostructures, but he also worked on a collaborative project with the Oregon Institute of Neuroscience and started a consulting company to fulfill a local industry need for physical modeling of stream temperature. The UO is also where Mick met his wife Liz, who is an R.N. and clinical instructor for the Nursing Program at UCC. Raising their two young children has reduced time spent climbing, but provided a whole new source of interest in both neuroscience and the physics of the human body.

PART I.

UNIT 1: PURPOSE AND PREPARATION

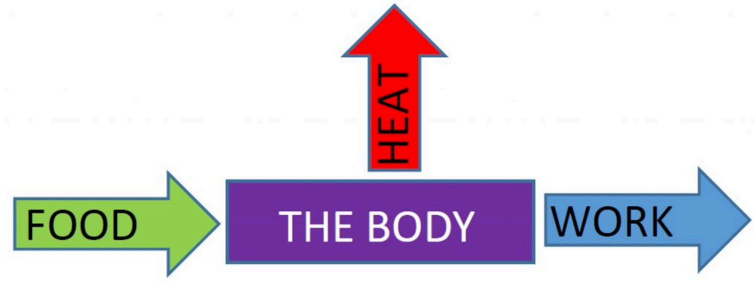
Unit 1 Learner Outcomes [No specific alignment with example course outcomes]

1. State the most basic purpose of the human body from a physics viewpoint.
2. State the purpose of this textbook.
3. Identify barriers to academic success and evaluate strategies to overcome barriers.
4. Explain the course expectations, including cognitive level and time commitment.
5. Provide an example study strategy that incorporates feedback and metacognition.

CHAPTER 1.

THE BODY'S PURPOSE

In order to accomplish your goals in life you must do a lot of work. Not work in the economic sense, but work in the scientific sense, which means to transfer energy from one form to another by application of a force over some distance. The purpose of this work includes, but is not limited to; the regulation of temperature, maintaining chemical concentrations, blood circulation, breathing, nerve impulse production, physical movements, and manipulation of environmental objects. A side-effect of doing all this work is the production of thermal energy which you release to your environment as heat. The combination of doing work and generating heat depletes your internal energy reserves, requiring you to take in more chemical energy (food). The purpose of the human body is to facilitate the body’s energy pathway, (energy input, energy storage, work output, and heat release), in order to maintain the conditions necessary for life and allow you to accomplish those things which are important to you.

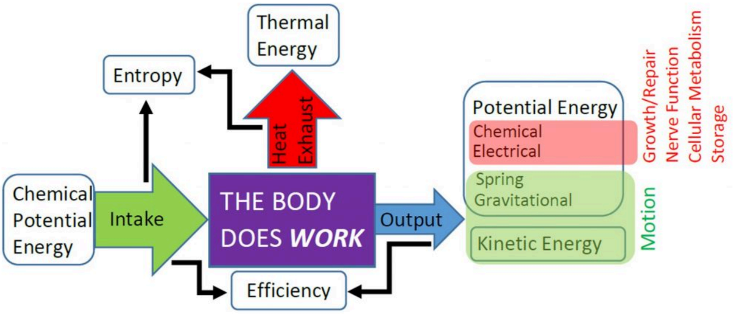


The basic energetic functions of the human body. This book will discuss the physics concepts behind this diagram, in addition to many others. The diagram will acquire more detail as we go along, eventually morphing into the complete concept map shown in the next Chapter.

CHAPTER 2.

THE PURPOSE OF THIS TEXBOOK

In order to understand why living requires work, and exactly how you get that work done, we need to understand the concepts of work, energy, and entropy. These happen to be some of the most fundamental concepts in all of physics. This textbook will introduce you to these fundamental concepts by analyzing the functioning of your own body. Along the way we will also learn about other physics concepts that help us to understand how we move, respond to forces, sense changes to our environment, and manipulate objects.



The most basic functions of the human body mapped to the main concepts covered in this text. Many of these terms might be new to you, but don't worry, this is just a preview. Later you will examine the similarities between this type of diagram for the human body and that of heat engines, such as the internal combustion engines, which power most vehicles.

CHAPTER 3.

PREPARE TO OVERCOME BARRIERS

Everyday Example

This term Jesse is taking two online courses and a face-to-face science course with a lab, so he will need to be on campus four days per week. Jesse lives and works in a rural area 20 miles from campus and there is no bus system between his home and campus. Jesse has a vehicle, but it's not very reliable and he expects that he won't make it through the term without a breakdown. Most of his money will go to tuition, gas and rent so Jesse does not have money available for a new vehicle, but he is usually able to make minor repairs within a few days when breakdowns happen to keep the vehicle running. Jesse has identified a breakdown as a possible barrier to his academic success, but he doesn't want to let that barrier stop him. Jesse is brainstorming things he can do now in preparation for meeting and defeating this barrier. Do you have any ideas?

Reinforcement Exercises

You are completely capable of being successful at physics, but that success will not come without time and effort. Life will present you with barriers to success and some of those barriers will not be under your control. You may not be able to remove them, so you will need to work with your instructor, advisor, family, and co-workers to find ways to get over, under, around, or straight through them. The information following sections and the activities at the end of the chapter will help you to define what success in this course means to you and identify barriers to that success. The activities will also prepare you to most efficiently apply your valuable time and effort to achieving your success.

An interactive or media element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bodyphysics/?p=181

CHAPTER 4.

PREPARE TO STRUGGLE

The goal of science is to find answers to questions. In order to accomplish that goal, scientists discover questions we don't have answers for, figure out what work needs to be done to find the answers, and then do that work. We will examine the scientific process in more detail at the end of chapter two, but essentially doing science means starting out confused and then thoughtfully struggling through steps necessary to become unconfused. That also happens to an effective approach for in-depth learning on many topics[1].

Everyday Example

Jamie works at a small business owned by a family friend. The owner told Jamie that another friend used a spreadsheet to track the budget for his own business and that it was helpful in keeping costs down and doing taxes. Jamie's boss assumed that because she was

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1. "The Importance of Failure in Learning" by David Freyberg, Tomorrow's Professor , Stanford University

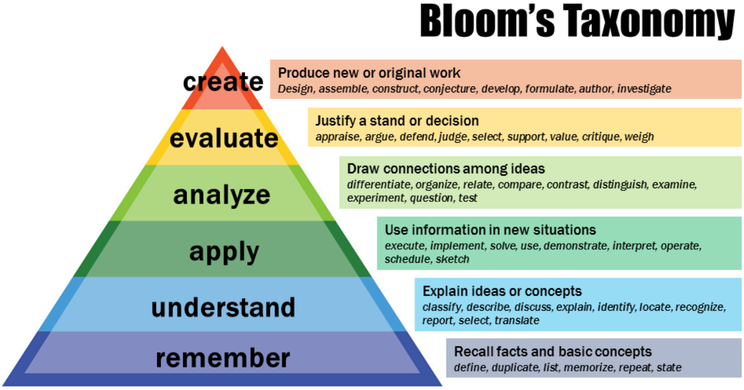
young she would be good with computer stuff so he offered Jamie some extra pay to make a spreadsheet and start tracking the budget for the business. Jamie was excited about the extra pay and putting budget management on her resume, and she wanted to impress her boss, but she had never worked with spreadsheets before and that worried her. Jamie decided she would just have to learn, and quickly. Jamie found a free spreadsheet program online and tried working with it, but it was too complex to figure out by trial and error and she felt frustrated that she was wasting time. In order to get the sheet done as quickly as possible Jamie tried searching the program's help feature for the specific operations she wanted to do, but she didn't even really know what words to search for. Also, it felt like the help pages were written for someone who already knew the basics of the program and it was a struggle to follow the examples. Jamie thought it wouldn't take long if she asked some of her friends who were into computer stuff for help, but they just ended up taking the mouse and doing things for her with little explanation and too fast for her to follow along or remember later. Jamie did get some parts of the sheet completed quickly this way, but she didn't learn much and wouldn't be able to finish, adapt, or improve the sheet on her own. Jamie worried that she might make a mistake in the budget later on if she relied too heavily on her friends. Jamie was really frustrated, but not yet ready to give up. Jamie searched the web for help with spreadsheets and found some video tutorials. It took some time to figure out which videos were for beginners, but she eventually found some. Being able to pause the video and repeat the operations in her own spreadsheet was slow, but really helpful. After a couple of hours she understood the basics of the program and had built a simple budget spreadsheet. As she worked to adapt her program to her specific business Jamie found that she could now effectively use the help feature of the program, which allowed her to make a lot of progress. Jamie was able to add a function that automatically updated and graphed the business profits when new payments and expenses were added and that moment felt really great. Jamie wanted to add some fancy features to really impress her boss, and asked her friends for help. Jamie found that now she could usually follow along and had the confidence and the language to ask questions when she couldn't. In addition to creating an efficient spreadsheet and picking up a useful skill, Jamie learned that there isn't really a shortcut to learning something complex. Knowing that hard work and perseverance will be required, Jamie can actually save time by not trying to avoid the difficult and sometimes slow learning process.

Until the science fiction of implanting information directly into the brain becomes reality, we must all experience some amount of confusion, struggle and discomfort during any learning process, including during this course. Rather than fear struggling and being confused, recognize that when you are struggling is a part of in-depth learning. If you avoid struggling with a topic, you may learn it at a shallow level, but you avoid learning it in depth. Embrace your struggles in this course as an indicator that you are learning. Enjoy the *ah-ha!* moments of becoming unconfused.

CHAPTER 5.

PREPARE YOUR EXPECTATIONS

This course is an introductory level science course, which typically means the students are expected to remember, understand, apply, and at times analyze the concepts covered in the course. These expectations correspond to the first four levels of Bloom's Taxonomy, a tool for categorizing thinking and learning, also known as cognition. Further into your academic timeline you will take courses with higher numbers and greater focus on the upper levels. However, to better prepare you for success in a complex world, this course may also use guided projects to expose you to the higher level cognitive processes.



Vanderbilt University Center for Teaching

This course focuses on the lower portion Bloom's Taxonomy, but at times you will have the opportunity to analyze, evaluate, and create. Be sure to use your instructor as a resource while working at any cognitive level.

[1]

The following table uses the concept of conservation of energy to illustrate of how students might be expected to participate in each level of Bloom's Taxonomy within an introductory physics course.

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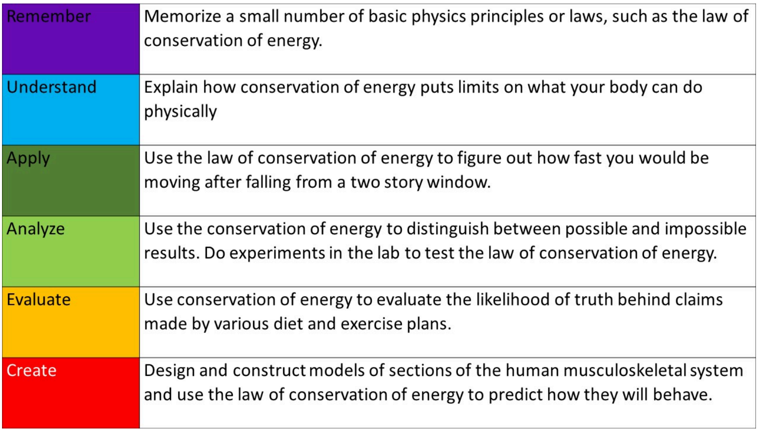
1. "Blooms Taxonomy" by Vanderbilt Center for Teaching and Learning is licensed under CC BY 4.0



Remember	Memorize a small number of basic physics principles or laws, such as the law of conservation of energy.
Understand	Explain how conservation of energy puts limits on what your body can do physically
Apply	Use the law of conservation of energy to figure out how fast you would be moving after falling from a two story window.
Analyze	Use the conservation of energy to distinguish between possible and impossible results. Do experiments in the lab to test the law of conservation of energy.
Evaluate	Use conservation of energy to evaluate the likelihood of truth behind claims made by various diet and exercise plans.
Create	Design and construct models of sections of the human musculoskeletal system and use the law of conservation of energy to predict how they will behave.

Connection of cognitive levels to various actions performed in this course.

Reinforcement Exercises

An interactive or media element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bodyphysics/?p=204

CHAPTER 6.

PREPARE YOUR STRATEGY

~~MULTITASKING~~

Humans can complete more than one simple task at one time, which is called multitasking. For example if you were to walk and chew gum you would be multitasking. However, multitasking when one or more of the tasks are even slightly complex rarely saves time and usually results in lower quality outcomes.

Reinforcement Activity

Use a stopwatch to time yourself while you write down each letter of the alphabet in a row and then below that write each number from 1-26 in a row. Record your time on your paper.

Next you will recreate the same two rows of letters and number as before, only this time you will write a letter on the top row, then a number below, then a letter above, and so on. You've already done this once so if multitasking really is more efficient then you should be faster this time. Record your time for this trial.

Were you faster when multitasking? Was the quality of your work higher?

Don't multitask when studying. Spend at least twenty minutes of focused work on a single topic, then take a few minutes of relaxed reflection on your work before moving on to a new task. Even listening to music might be distracting if you are actively listening to the lyrics or trying to decide if you like the song. If you notice yourself thinking about the music and not the subject you are studying, you may need to try something new.

FEEDBACK

While new to a topic you don't yet have the tools to correctly evaluate your own progress toward understanding. Put simply, ***when first starting out you don't know what you don't know, which can lead to overestimating your level of preparation*** until after an exam or other heavily weighted assignment. Receiving feedback on your progress early and often will help you to avoid this barrier to success. Your instructor might provide early and often feedback in the form of quizzes, online homework, tutorials, in-class practice problems, and clicker questions, to name a few. You should actively seek out early and often feedback by attempting the example problems in the book before looking at the solutions, starting your homework early, and asking questions during your instructor's office hours.

In order to make the most of the feedback you receive you should practice metacognition. In other words, don't just think, also think about how you are thinking[1]. When learning something new, consider why you are going to learn it. Make a plan for how to learn it. Assess your progress in learning it and identify ways to improve your plan. When you think you already know something, stop and ask yourself how, why, and when you came to know it. Reflect on what information that knowledge is based, where the information came from, and how you might verify the information. Metacognition can help you recognize when you don't yet have enough information to make a good decision, so it might significantly improve your learning and help you avoid barriers to success, both in school and in life. For more information check out this detailed resource on metacognition.

STUDY STRATEGY

You should adopt a study strategy that avoids multitasking, but includes early and often feedback along with meta-cognition (just by reading this section you are already engaging in light metacognition). Start by first attempting to understand concepts with aid from various resources. Assess your knowledge by applying it to new situations, and then use the assessment results for metacognition. Seek help from your instructor on concepts that aren't yet clear. Review material that you figured out you don't yet know, and then repeat. The various activities in your courses are already structured to facilitate exactly that process. The diagram below is an example study cycle that would likely be effective in most science courses. Notice that the majority of activities provide feedback. Anytime feedback is provided you should employ metacognition and evaluate the

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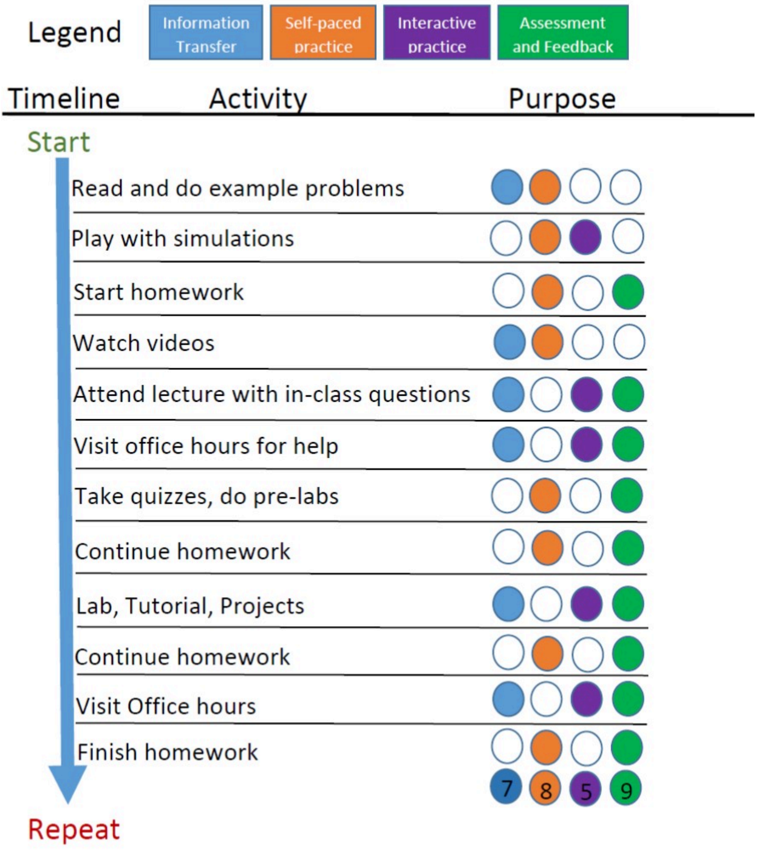
1. "Metacognition" by Nancy Chick, Vanderbilt Center for Teaching and Learning is licensed under CC BY 4.0

effectiveness of your study methods. The chart that follows gives specific tips on maximizing the impact of each part of the cycle.



Legend 🔵 Information Transfer 🟠 Self-paced practice 🟣 Interactive practice 🟢 Assessment and Feedback

Timeline	Activity	Purpose
Start		
	Read and do example problems	🔵 🟠 ○ ○
	Play with simulations	○ 🟠 🟣 ○
	Start homework	○ 🟠 ○ 🟢
	Watch videos	🔵 🟠 ○ ○
	Attend lecture with in-class questions	🔵 ○ 🟣 🟢
	Visit office hours for help	🔵 ○ 🟣 🟢
	Take quizzes, do pre-labs	○ 🟠 ○ 🟢
	Continue homework	○ 🟠 ○ 🟢
	Lab, Tutorial, Projects	🔵 ○ 🟣 🟢
	Continue homework	○ 🟠 ○ 🟢
	Visit Office hours	🔵 ○ 🟣 🟢
	Finish homework	○ 🟠 ○ 🟢
		7 8 5 9
Repeat		

Effective study cycle. the color coded legend bubbles indicate the purpose behind activities in introductory courses. The totals at the bottom indicate the number of activities that fulfill each purpose. Notice that most activities provide some form of feedback that can be used in a metacognitive process.

WATCH	Write down questions about what you didn’t understand. Write down words and concepts that seem important so that you can look for those during lecture and while reading.
ATTEND	Attend lectures and pay attention. Ignore your phone and stay awake. Try **not** to take comprehensive notes. Instead actively process lecture material by relating it to your own experiences, anticipating the instructor’s next move, participating in practice calculations, and asking questions. Only write down the most important and most confusing ideas so you can revisit them later.
READ	Use the textbook/instructor’s notes as your primary resource, not your own notes. Read the chapter outcomes so you know what you are expected to learn Look up words you don’t know and write down questions you have so you can ask during lecture or office hours. Look out for the concepts you wrote down from videos and lecture. Don’t skip example problems and example scenarios. If a question is asked, stop and answer it out loud or in writing.
ASSESS	Do what you can to contribute equally to labs and projects. Check to see if you can explain to others how lab activities and projects are related to specific concepts. Try to solve example problems in the book without looking at the solution first. Start your homework early. See how far you can get on your own before asking for help. Use this as an indicator of gaps in your knowledge. Ask your instructor or a tutor for homework help before asking classmates. They will help you fill in knowledge gaps differently than classmates will. Work on homework with your classmates. Don’t look at solutions from classmates who are already finished or solutions posted/provided on-line. These will prevent you from accurately evaluating your level of preparation. Take in-class questions and quizzes seriously. Use your scores to tell you what you need to study again. Check your overall grade often and talk with your instructor about your progress and your goals.

ADJUST	Use your exam and overall grade to determine if your study strategy is working. Ask your instructor for help making adjustments if it's not.
REVIEW	Use the results of your evaluations to determine what specific material you need to review and ask your instructor about.
REPEAT	Repeat this cycle for each week, chapter, module, or other method of organizing material used by your instructor. You should also repeat the previous three steps prior to an exam.

CHAPTER 7.

PREPARE YOUR SCHEDULE

We now see that applying an effective study cycle takes time and effort. Most students find that college academics requires significantly more time and effort than high school academics. The difference in time and effort expectations between new students and instructors sometimes creates a barrier to success. Avoid this barrier by talking with your instructor about their expectations. Then follow the numbered instructions below to create a schedule to help you determine what time you have available to study. Your school may use an online learning management system (LMS) such as CANVAS or Blackboard, which probably has a scheduling feature that automatically populates your courses so all you have to do is add in your other commitments and study time. Otherwise, just use your favorite calendar app or planner, or print off a free weekly planner, or ask your instructor for help creating your schedule using a spreadsheet, or try one of these free online schedulers designed for college students:

https://freecollegeschedulemaker.com/
https://www.mystudylife.com/

https://www.canva.com/create/weekly-schedules/

Reinforcement Activity

1) First enter the obligations you already have, such as work, other classes, family obligations, athletic practices, and any others into your planner.

2) Next, find out how much time you will be expected to spend on each course outside of the classroom. The time will depend on the class level (number), the course credits, and your preparation and familiarity with the subject matter. Your instructor will be able to help you estimate this time.

3) Finally, incorporate your effective study cycle into your schedule. Identify time in your schedule to complete each part of your study cycle.

4) Also schedule time for other things that may be important to you, such as exercise or time with friends. If there isn't enough time for everything, you will need to prioritize. Simply neglecting some of your obligations is not a good strategy and will not lead to success.

5) If you discover that you are short on time and some prioritization is necessary, work with your instructor and your advisor, as well as family and work, to ensure that you have enough time to meet all of your obligations.

CHAPTER 8.

UNIT 1 REVIEW

Key Terms and Concepts

- Energy Pathway
- Barriers
- Cognition
- Blooms Taxonomy
- Multitasking
- Feedback
- Metacognition
- Study strategy

Unit 1 Learner Outcomes [No specific alignment with example course outcomes]

1. State the most basic purpose of the human body from a physics viewpoint.
2. State the purpose of this textbook.
3. Identify barriers to academic success and evaluate strategies to overcome barriers.
4. Explain the course expectations, including cognitive level and time commitment.
5. Provide an example study strategy that incorporates feedback and metacognition.

CHAPTER 9.

UNIT 1 PRACTICE AND ASSESSMENT

Outcome 1

1) Diagram the energy pathway of the human body at the most basic level. Label each of the three basic processes with an example from earlier today of how that process happened for you.

Outcome 2

2) State three basic concepts studied in physics and covered in this textbook.

3) Browse the table of contents and state which topic covered by this book looks most interesting to you and why.

Outcome 3

4) Identify three possible barriers to your academic success.

5) Provide a possible solution to each of three barriers to academic success.

Outcome 4

6) Identify at least two important differences in academic expectations and/or academic structure between high school and college.

7) What is the highest level of cognition at which you have operated? Was it at home, school, work, or during military service? Explain the situation using terms from Bloom's Taxonomy.

8) Explain how you acquired the experience, skills, and knowledge necessary to operate at the cognitive level you described in the previous question. Were you born with it, just acquire it suddenly one day, or did you acquire it gradually over time? Did it take effort or was it easy?

Outcome 5

9) Apply metacognition to some information from outside this course that you might already understand. State the information, explain how you applied metacognition, and then explain how metacognition affected your original understanding.

10) Build your personal study strategy for this course. The strategy should include activities like reading, working examples, video watching, homework, office hour visits, exam preparation, etc.

a) First enter the obligations you already have, such as work, other classes, family obligations, athletic practices, and any others into a planner.

b) Next, find out how much time you will be expected to spend on each course outside of the classroom. The time will depend on the class level (number), the course credits, and your preparation and familiarity with the subject matter. Your instructor will be able to help you estimate this time.

c) Finally, incorporate your effective study cycle into your schedule. Identify time in your schedule to complete each part of your study cycle.

d) Also schedule time for other things that may be important to you, such as exercise or time with friends. If there isn't enough time for everything, you will need to prioritize. Simply neglecting some of your obligations is not a good strategy and will not lead to success.

e) If you discover that you are short on time and some prioritization is necessary, work with your instructor and your advisor, as well as family and work, to ensure that you have enough time to meet all of your obligations.

PART II.

UNIT 2: MEASURING THE BODY

Unit 2 Learner Outcomes

1. Describe the scientific method through an original example of how it could be applied to the student's everyday life. [5]
2. Identify the differences and relationships between empirical models, physical models, hypotheses, theories, and laws. [5]
3. Find necessary conversion factors and convert between SI and non-standard units for several physical quantities. [1]
4. Perform order of magnitude estimation. [2]

CHAPTER 10.

JOLENE'S MIGRAINES

Jolene is a Registered Nurse (RN). After taking time off to have her first child she returned to work. She *observed* that she had migraines of varying severity every time she worked a twelve hour shift. She was able to fight through the migraines and do her job, but it was difficult, painful, exhausting, and possibly dangerous.

Jolene wondered what was causing the migraines. To answer this *question* she *gathered available knowledge* from friends and co-workers, the internet, and her health care provider. These sources gave many possible reasons for migraines[1]. Jolene had taken science courses in preparation for nursing school, so she knew the best way to determine the cause was to use the scientific method. She evaluated the list and eliminated the possible test conditions that didn't apply or that she couldn't change:

Jolene's Table of Possible Migraine Causes

Possible Cause	**Reasoning**	**Readily Testable?**
Dehydration	*she rarely had time to stop for water during shift*	Yes

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[1] "Migraine" by U.S. National Library of Medicine

~~Caffeine withdrawal~~	*she drank coffee at work*	No
~~Changes in hormone levels~~	*she was breastfeeding, but didn't want to stop*	No
Changes in sleep patterns	*she did go to bed and get up earlier for shifts*	Yes
~~Drinking alcohol~~	*she didn't drink*	No
~~Exercise or other physical stress~~	*on her feet 12 hours, but no control of that*	No
~~Loud noises or bright lights~~	*the hospital lights are bright, but no control*	No
Missed meals	*she often didn't have time to eat meals on shift*	Yes
~~Odors or perfumes~~	*no control of the hospital smells*	No
~~Smoking or smoke exposure~~	*not in the hospital*	No
~~Stress and anxiety~~	*definitely, not much control*	No
~~Certain foods~~	*she missed meals, but didn't eat different foods*	No

Each of the three variables remaining on the list could be tested, so each one could be used in a hypothesis. One-by-one Jolene would hypothesize that a test condition was the cause and then test the hypothesis by changing only that one condition and observing how it affected her migraine. For example her first stated hypothesis could be: *dehydration is contributing to my migraines.* Her first test could be to stay well hydrated and observe how it affected her migraines. Sometimes it's easier to compare results with a null hypothesis, which in this case would be: *hydration level does not affect my migraines.*

Jolene realized that more than one variable could be contributing to her migraines, and that changing one might only affect the severity of her migraines rather than prevent them, so she needed to do more than just observe, she needs to make a *measurement* of migraine severity. She decided to use the Wong-Baker 1-10 Pain Scale as her measurement tool (instrument). She calibrated the scale with childbirth on the top, no pain on the bottom, and stepping on a Lego in the middle.

Finally, Jolene decided she would make multiple tests of each hypothesis by rotating through them. First, she kept track of her scores for the first week, but didn't change her behavior. This was the first control week. The next week she made sure to drink more water, followed by a week of going to bed and getting up at the same time every day, and finally she made sure to have quick foods ready for breaks all of the third week. Jolene repeated the cycle for 12 weeks, and kept track of her data in a table. To analyze the data she and added up the pain scores for the three shifts each week and put those results into a table.

Table of Jolene's Weekly Pain Scale Totals

Test Condition	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	We 11
Control	25				22				27		
Hydration		24				26				21	
Consistent Sleep			18				20				19
Nutrition				23				27			

Reinforcement Activity

Just as we saw from Jolene's example, the basic scientific method is: *Observe,* ask a *question,* formulate a hypothesis, use the hypothesis to make a *testable prediction, test* the prediction experimentally, analyze results, *compare* prediction to test result, and formulate a conclusion.

This example is based on actual events, but names have been changed. The real-life Jolene concluded that a consistent sleep schedule was the most important factor. She then committed to getting up every day at the same early time as she did on works days, even if she didn't have work. After about three weeks her migraines leveled out at about one low-severity migraine per month.

Most of the information that we use in this textbook, from the amount of force that bones can support to the amount of energy contained in various foods, was determined by scientists using the scientific method, but maybe not in exactly the same way that you learned in middle school.

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CHAPTER 11.

THE SCIENTIFIC PROCESS

SCIENCE AS A CYCLE

The scientific method alone is not enough to make real progress in accumulation of scientific knowledge, but using it as the hub of a cyclic process has led to the massive rate of scientific and technological advancement we have seen over the last century. Science can be thought of as a continuous process guided by with the scientific method as discussed in the following video:

Reinforcement Exercise

Modern science is done according to a complex process of checks and balances, such as replication and peer-review. This complexity emerged to help ensure the integrity of scientific results, but the process remains rooted in the basic scientific method. You can apply the basic scientific method every day, just as Jolene did, in order to ensure that you make informed decisions that aren't overly biased by inaccurate data, false logic, or your own preconceptions.

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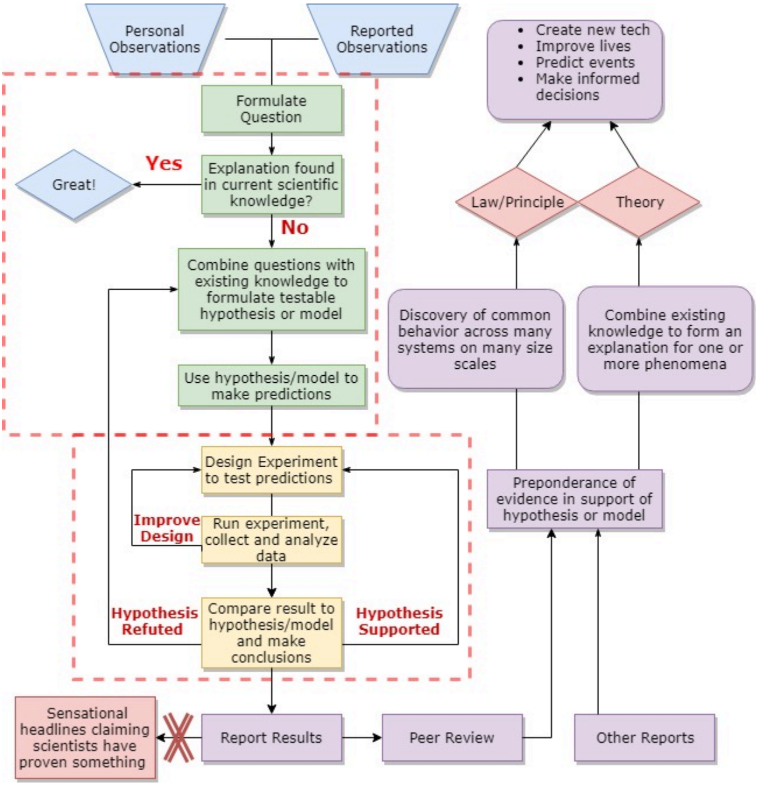
An interactive or media element has been excluded from this version of the text. You can view it online here:
https://openoregon.pressbooks.pub/bodyphysics/?p=196



The complex modern scientific process built around the basic scientific method (within dashed lines).

The previous diagram illustrates the complex scientific process, but also highlights the basic scientific method that Jolene used in the previous example, on which the whole process is built. After observation, the basic scientific method follows the green and yellow boxes within the dotted line in the diagram below. Generally speaking, the green boxes comprise theoretical science and the yellow boxes comprise experimental science. These days most scientists participate in some or all parts of both categories and collaborate with other scientists to complete the process.

The uncertainty associated with all measurements means that science cannot *prove* anything, despite what the media often claims. Instead, the scientific process produces reviewed and reproduced conclusions that account for uncertainty. (We will learn how scientists recognize and deal with uncertainty in the next chapter). Scientific conclusions provide evidence for or against hypotheses.

LAWS, PRINCIPLES AND THEORIES

LAWS

When a certain behavior is repeatedly observed across many systems of many sizes and time periods, then the behavior becomes a law. A law is not an *explanation* of the observed behavior. For example, the 1st Law of Thermodynamics states that the when a system does work and/or loses heat, the internal energy of the system must drop by an amount equal to the work done plus the heat lost.

PRINCIPLES

Principles summarize rules created based on collections of laws and followed by scientists when formulating hypotheses, designing experiments, analyzing results. For example, the principle of conservation of energy states that energy cannot be created or destroyed, only transferred. The 1st Law of Thermodynamics supports the principle of conservation of energy.

THEORIES

When a preponderance of evidence supports a particular *explanation* for observed occurrences (phenomena), then the explanation becomes a theory. Laws, principles, and theories are what the general public and media often refer to as scientific facts, but we don't need to introduce another definition so we won't use fact here. We will combine and apply a variety of laws, principles, and theories to understand how the body functions.

Reinforcement Exercises

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CHAPTER 12.

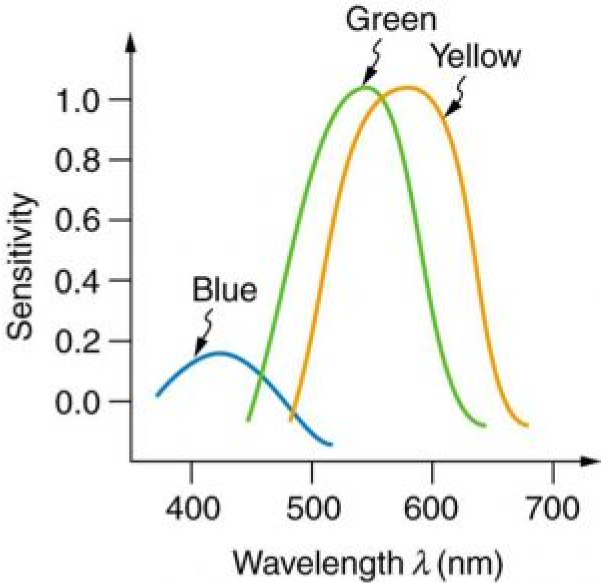
SCIENTIFIC MODELS

PHYSICAL AND EMPIRICAL MODELS

A model is a representation of something that is often too difficult (or impossible) to observe or display directly. Although a model is justified by experimental tests, it is only accurate in describing certain aspects of a physical system. For example, a basic model of color vision which accounts for the response of the eye to different colors, but not for the processing of that information by the brain[1]Such a model is not all-encompassing, but it is still useful in many situations, such as designing digital displays or creating a computer simulation to predict the results of various color combinations. Check out this interactive simulation of color vision.

---

1. [1] OpenStax University Physics, University Physics Volume 1. OpenStax CNX. Jun 5, 2018http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@10.16.



The graph shows the relative sensitivity of the three types of cones, which are named according to light wavelengths (colors) of greatest sensitivity. Evidence for the three types of cones comes from direct measurements in animal and human eyes and testing of color blind people. Image Credit: OpenStax College Physics

Widely applicable Physical models (mechanistic models) that explain how a system works, like the color vision model, can become theories after a preponderance of evidence has been built supporting their validity. Empirical models, which use mathematical trends in observed data, cannot become theories, but they are still useful for making decisions once they have sufficiently been validated.

QUALITATIVE AND QUANTITATIVE MODELS

Both physical and empirical models can be either qualitative or quantitative. Qualitative models predict what behavior you expect to observe, while quantitative models predict behaviors to observe and actual values of measurements. The following table will help you understand the different types of models. The amount of information provided by the model increases as you move from upper left to lower right of the table.

Examples of Models to Explain Observations of Falling Objects.

	Empirical	**Physical (Mechanistic)**
Qualitative	In the absences of air resistance, objects dropped from the same height will hit the ground at the same time, no matter what the objects are.	When you drop something it falls due to mutual gravitational attraction with the Earth. More massive things feel a greater attraction, but they are also more difficult to accelerate, so everything ends up accelerating at the same rate.
Quantitative	Without air resistance, everything falls with the same acceleration value of 9.8 **m/s/s**.	Combining Newton's Law of Universal Gravitation and Newton's 2nd Law of Motion, to predict that the free-fall acceleration for objects at the surface of the Earth should be 9.8 **m/s/s**. (And it is!).

Stay tuned, the Unit 2 lab will produce a *quantitative empirical model* for the fall time of certain objects from a certain height when air resistance is present.

COMPUTER MODELS

Computer modeling is a relatively new tool for science, but it still fits right into the overall process. Computer models are often used to assist in making predictions to be tested experimentally. Sometimes computer models are used as surrogates for expensive, time consuming, or complex, experiments to inform the experimental design process. However computer models are not permanent substitutes for experimentation and the results of computer models should be verified by experimentation or observational data. Computer models which have been verified against data are exceptionally helpful in making predictions used in decision making. For example modeling high altitude winds to plan airliner flight paths and modeling storm paths to plan emergency procedures.

Reinforcement Exercises

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CHAPTER 13.

MEASURING HEART RATE

UNITS

Working as a nurse, one of the most common measurements Jolene takes is heart rate. Heart rate is often measured by counting the number of pulses that occur in the wrist or the neck over a specified amount of time. In order to compare heart rates measured by different people we need to be sure that everyone is using the same measurement units. The medical field uses beats per minute (**BPM**) as the standard unit for heart rate measurements.

UNIT CONVERSION

Rather than waiting and counting pulses over a full minute, you can make the measurement more quickly by counting pulses for six seconds and then multiplying the number by ten, to get the number of pulses that would have occurred in sixty seconds, or one minute. This process is known as *unit conversion* and the number ten was the conversion factor for this example.

Everyday Example: Heart Rate

Carlotta wants to determine her heart rate in **BPM**. She counts nine pulses in six seconds. She then uses a conversion factor of ten to convert from beats per six seconds to **BPM** and determines her heart rate to be 90 **BPM**:

$$(9\,beats\,per\,six\,seconds) \times 10 = 90\,\mathbf{BPM}$$

The chain-link method of unit conversion prevents mistakes by keeping track of all the values, units, and conversion factors.

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To apply the chain-link method:

1. Write down the original value and units.
2. Set this equal to itself, only now with units written as a fraction.
3. Multiply by conversion factors to cancel undesired units and leave only desired final units.
4. Invert some conversion factors to get the undesired units to cancel, if needed.
5. Multiply the numbers across the top.
6. Multiply the numbers across the bottom.
7. Divide the top result by the bottom result.
8. Record the final value.
9. Add on the desired final units (top and bottom) that are left over after cancelling.

Applying the chain link method to the previous example gives us the same answer, only now we don't need to just know ahead of time that we should multiply by ten, we only needed to know there are 60 seconds in one minute, which we use as our conversion factor.

Everyday Example: Heart rate

Carlotta wants to determine her heart rate in **BPM**. She counts nine pulses is in six seconds. She then uses a conversion factor of ten to convert from beats per six seconds to **BPM** and determines her heart rate to be 90 **BPM**:

$$9\,beats\,per\,six\,seconds = \frac{9\,beats}{6\,\cancel{seconds}}\left(\frac{60\,\cancel{seconds}}{1\,minute}\right) = \frac{9\,beats \times 10}{minute} = \frac{90\,beats}{minute}$$

$$= 90\,\mathbf{BPM}$$

Applying the chain link method to the previous example gives us the same answer, only now we don't need to know ahead of time that we should multiply by ten, we only needed to know that were 60 seconds in one minute, which we used as our conversion factor.

The act of ensuring that your answer to a problem has the correct units is called unit analysis. The term chain-link method is often used interchangeably with the terms unit analysis or dimensional analysis, such as in this helpful video demonstrating unit analysis with the chain-link method. Let's practice some more unit conversion using the chain-link method with multiple conversion factors:

Everyday Example

Ronnie wants to estimate how much money he will spend on gas driving back and forth from campus this term. A round-trip to campus is 14.2 miles, his car typically gets 27 miles per gallon (**MPG**) and gas is currently **$**2.86 per gallon. He needs to drive to campus and back four times per week. Let's predict his cost for gas during the 11 week term.

$$11\,weeks\,per\,term = \left(\frac{11\,weeks}{1\,term}\right)\left(\frac{4\,trips}{1\,week}\right)\left(\frac{14.2\,miles}{1\,trip}\right)\left(\frac{1\,gallon}{27\,miles}\right)\left(\frac{2.86\,dollars}{1\,gallon}\right)$$

$$= \left(\frac{66.18\,dollars}{1\,term}\right) = 66.18\,Dollars\,per\,term$$

STANDARD UNITS

Similar to medical professionals, scientists use standard scientific (SI) units when reporting measurements so we can all stay on the same page. For example, the fundamental SI unit of time is seconds. In this course we will primarily use seconds for time, meters for length, kilograms for mass, and Kelvin for temperature. All of the other units we use will be combinations of these few fundamental SI units. The table below shows all seven of the fundamental SI units and their abbreviations[1]. All other standard scientific units are derived units, meaning they are combinations of those seven fundamental units. Throughout this book abbreviated units will be **bold** for clarity. The seven fundamental units and their abbreviations are summarized in the following table. Visit the National Institute for Standards and Technology (NIST) for more information on standard units.

Table of the fundamental International Standard (SI) units

Property	Unit	Abbreviation
Length	meter	**m**
Mass	kilogram	**kg**
Time	seconds	**s**
Number (Amount)	mole	**mol**
Temperature	Kelvin	**K**
Electrical Current	Ampere	**A (amp)**
Luminous Intensity	candella	**cd**

As with heart rate, the standard medical units and

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[1] Abozenadah, H., Bishop, A., Bittner, S., Lopez, O., Wiley, C., and Flatt, P.M. (2017) Consumer Chemistry: How Organic Chemistry Impacts Our Lives. CC BY-NC-SA. Available at: http://www.wou.edu/chemistry/courses/online-chemistry-textbooks/ch105-consumer-chemistry/

standard scientific units don't always match up, which means that we will need to be skilled in unit analysis and unit conversion if we want to use physics to analyze the human body. Let's practice again.

Everyday Example: Units for speed

Aasma ran as fast as she could while a friend drove alongside in a car with the speedometer reading 14 miles per hour (**MPH**). Can you determine how fast Aasma was running in units of meters per second (**m/s**)? There are 1.6 kilometers (**km**) in one mile (**mi**) and 1000 meters (**m**) in one kilometer. Remembering that there are 60 seconds (**s**) per minute (**min**) and 60 **min** per hour (**hr**).

$$14, \mathbf{MPH} = \left(\frac{14\,\mathbf{mi}}{1\,\mathbf{hr}}\right)\left(\frac{1.6\,\mathbf{km}}{1\,\mathbf{mi}}\right)\left(\frac{1000\,\mathbf{m}}{1\,\mathbf{km}}\right)\left(\frac{1\,\mathbf{hr}}{60\,\mathbf{min}}\right)\left(\frac{1\,\mathbf{min}}{60\,\mathbf{s}}\right)$$

$$= \left(\frac{6.2\,\mathbf{m}}{\mathbf{s}}\right) = 6.2\, meters\, per\ second$$

Reinforcement Exercises

An interactive or media element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bodyphysics/?p=251

CHAPTER 14.

HEART BEATS PER LIFETIME

ESTIMATING LIFETIME HEART BEATS

In addition to pb_glossary id="3761″]unit analysis[/pb_glossary] with the chain-link method can also help us to answer difficult questions. For example, calculating how many heart beats an average person experiences during their lifetime seems daunting. With the chain-link method we can come up with an estimated value relatively quickly. A search of the internet finds that the average life expectancy in the U.S. is 78.8 years[1] and that the typical value for adult heart rate is between 60 **BPM** and 100 **BPM**[2] so let's take the middle-range value of 80 **BPM** and go from there.

---

1. "Mortality Data" by National Vital Statistics System, Centers For Disease Control and Prevention
2. "Pulse" by Pubmed Health, U.S. National Library of Medicine

Everyday Examples: Heart Beats Per Lifetime

We start with the average lifespan, which we will round to 80 years for simplicity:

$$80\,\mathbf{yr} = 80\,\cancel{\mathbf{yr}}\left(\frac{365\,\cancel{days}}{1\,\cancel{\mathbf{yr}}}\right)\left(\frac{24\,\cancel{\mathbf{hr}}}{1\,\cancel{days}}\right)\left(\frac{60\,\cancel{\mathbf{min}}}{1\,\cancel{\mathbf{hr}}}\right)\left(\frac{80\,\cancel{beats}}{1\,\cancel{\mathbf{min}}}\right) = 3,363,840,000\,beats$$

We have estimated that one lifetime will contain over three billion beats!

That's a big number! In fact, it's over three billion beats. As it turns out, humans are quite special among animals in the number of heartbeats per lifetime we experience. Visit the website of the beats per lifetime project[3] for more information and an interactive look at heart rate statistics for various species.

In the previous calculation we chose to use a heart rate of 80 **BPM**, which was an approximation rather than an actual measurement or calculation. Therefore, our answer is only an estimate. However, we don't expect anyone who lives to adulthood will get anywhere near 10x more or 10x fewer beats than this, so our answer is within an order of magnitude of what most people experience. Combining several already known, easily found, or approximate values to get a general idea of how big an answer should be, as we just did for beats per lifetime, provides an order of magnitude estimation. Play

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3. "The Heart Project" by The Heart Project, Rob Dunn Lab

with this simulation to practice estimating sizes using only visual cues.

ESTIMATION AND APPROXIMATION

Order of magnitude estimation often relies on approximate values, so *order of magnitude estimate* and approximation are often used interchangeably. Adding to confusion, approximation is often used interchangeably with assumption or uses approximation to describe a quick, rough measurement with a high degree of uncertainty. In order to maximize clarity this textbook will strive to stick to using terms as defined according to the following table.

Term	**Definition**	**Everyday Example**
Assumption	Ignoring some compilation of the in order to simplify the analysis or proceed even though information is lacking. Scientists state assumptions, justify why they were needed, and estimate their possible impact on results.	My cotton clothes are completely soaked through, so I assume they are not providing any insulating effect against the cold water.
Approximation Approximate	Act of coming up with a rough value using prior knowledge and assumptions, but not by making a measurement for the purpose of determining the value.	The water feels cold, but not shocking, similar to the 70 **°F** swimming lake, so the approximate water temperature is 70 **°F**.
Uncertainty (more about this later)	Amount by which a measured, calculated, or approximated value could be different from the actual value.	85 **°F** would feel comfortable like the 82 **°F** college pool and 55 **°F** feels very cold, so + 15 **F°** is my uncertainty from 70 **°F**.
Order of Magnitude Estimate	Result of combining assumptions, approximate values, and/or measurements with large uncertainty to calculate an answer with large uncertainty, but has the correct order of magnitude.	Using known data, I estimated my time to exhaustion or loss of consciousness to be 5 hours (less than 50 hours and more than 0.5 hours).

METRIC PREFIXES

Considering that our beats per lifetime answer is only an order of magnitude estimation, we should round our final answer to have fewer significant figures. Let's make it 3,000,000,000 beats per lifetime (**BPL**), or three billion **BPL**. A bit later in the chapter we will define what we mean by and significant figures and also talk more about why, when, and how we have to do this kind of rounding. For now, we notice that it's a bit distracting and a bit annoying writing out all those zeros, so by counting that there are nine places before the first digit we can use scientific notation and instead write: 3×10^9 **BPL**. Alternatively we can use a metric prefix. The prefix for 10^9 is Giga (**G**) so we can write: 3 ***GBPL*** (read as gigabeats per lifetime). The table below shows the common metric prefixes. For a much more comprehensive list of prefixes visit the NIST website. One advantage of using metric units is that the different size units are related directly by factors of ten. For example 1 meter = 100 **cm** rather than 1 foot = 12 inches.

Table of Metric Prefixes and Representative Physical Quantities [1]

prefix	symbol	value	example (some are approximate)			
exa	E	10^{18}	exameter	Em	10^{18} m	distance light travels in a century
peta	P	10^{15}	petasecond	Ps	10^{15} s	30 million years
tera	T	10^{12}	terawatt	TW	10^{12} W	powerful laser output
giga	G	10^{9}	gigahertz	GHz	10^{9} Hz	a microwave frequency
mega	M	10^{6}	megacurie	MCi	10^{6} Ci	high radioactivity
kilo	k	10^{3}	kilometer	km	10^{3} m	about 6/10 mile
hecto	h	10^{2}	hectoliter	hL	10^{2} L	26 gallons
deka	da	10^{1}	dekagram	dag	10^{1} g	teaspoon of butter

prefix	symbol	value	example (some are approximate)			
–	–	10^0 =1	–	–	–	
deci	d	10^{-1}	deciliter	dL	10^{-1} L	less than half a soda
centi	c	10^{-2}	centimeter	cm	10^{-2} m	fingertip thickness
milli	m	10^{-3}	millimeter	mm	10^{-3} m	flea at its shoulders
micro	µ	10^{-6}	micrometer	µm	10^{-6} m	detail in microscope
nano	n	10^{-9}	nanogram	ng	10^{-9} g	small speck of dust
pico	p	10^{-12}	picofarad	pF	10^{-12} F	small capacitor in radio
femto	f	10^{-15}	femtometer	fm	10^{-15} m	size of a proton
atto	a	10^{-18}	attosecond	as	10^{-18} s	time light crosses an atom

Reinforcement Exercises

An interactive or media element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bodyphysics/?p=199

CHAPTER 15.

HUMAN DIMENSIONS

HEIGHT (LENGTH)

Height is a common body measurement typically measured in feet (**ft**) + inches (**in**) in the United States and centimeters (**cm**) elsewhere. These are length measurements, so the SI unit would be meters. Keep in mind that ***x*** feet + ***y*** inches is commonly denoted as ***x***‘ **y**“.

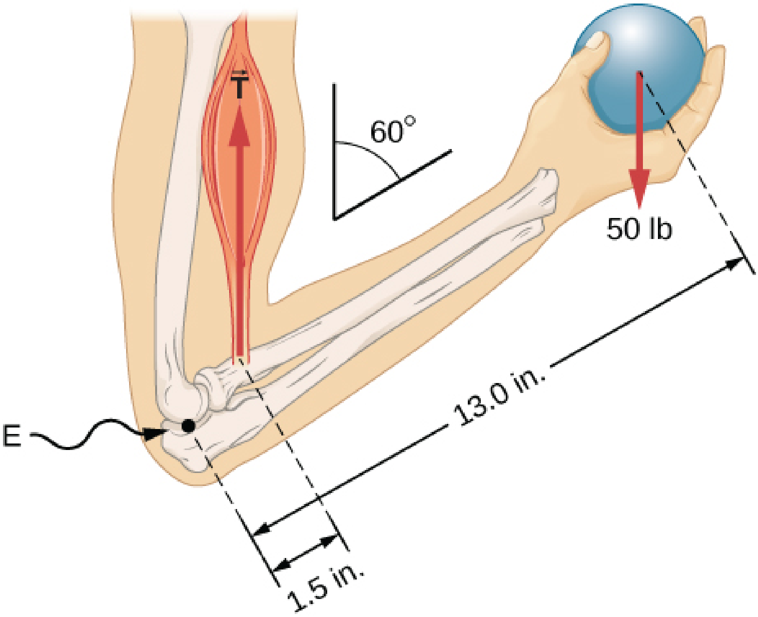
Reinforcement Activity

Given that there are 2.54 **cm** in one inch, 12 **in** per one **ft**, and 100 **cm** in 1 **m**, use the chain link method to convert your height from the type of units you are familiar with into the other two types (**cm**, **m**, or **ft** + **in**).

RANGE OF MOTION

Range of motion is a common body measurement, especially while diagnosing injury or disease, tracking progress during physical therapy, or working to improve flexibility or form. Range of motion is often defined as an angle measured in *degrees* (°)through which a joint moves away from a reference position as seen in this video demonstration of how to use a goniometer for range of motion measurement.

For example, in the image below the joint angle is 60° and the reference position is a nearly horizontal forearm creating a 90° between the bicep muscle and the bones of the forearm. (This is not necessarily how the reference angle is defined for measuring elbow range of motion by health professionals)



The elbow joint flexed to form a 60° angle between the upper arm and forearm. Image Credit: Openstax University Physics

1

At times we might want to know how far something moves as it travels through an angle. For example, as the arm in the image below moved from 90° to 60° what distance did the hand and ball cover? In such cases, and many others, working with angles in radians (rads) can be helpful. We can convert between degrees and radians using the conversion factor:

(1) $2\pi, radians = 360,$

For example, in moving from 90° to the 60° seen in the previous diagram, the lower arm traversed 30° so we can convert this to radians:

$$30^\circ = 30/\left(\frac{2\pi\, radians}{360/}\right) = 0.523\, radians = 0.523\,\mathbf{rads}$$

The distance we are trying to calculate is known as the arc length, and to find it we multiply the angle in units of radians by the distance from the rotation point (also known as the radius). The symbols commonly used for arc length, angle and radius are: ℓ, θ, and Γ so in our example we will have:

$$\ell = thetar = (0.523\,\mathbf{rads})\,(13\,\mathbf{in}) = 6.8\,\mathbf{in}$$

We have found that the hand moves a distance of 6.8 inches when the forearm moves from horizontal to 60° of flexion. We have also discovered that **rads** are a placeholder unit, meaning that when **rads** gets multiplied by another unit, **rads** doesn't necessarily show up in the final units. Finally, we realize that we need to start keeping track of which symbols are most commonly used for which quantities. The following table shows the symbols most often used for some of the common quantities that we will encounter in this textbook. As we

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1. OpenStax University Physics, University Physics Volume 1. OpenStax CNX. Jul 11, 2018 http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@10.18

introduce new quantities going forward we will provide the common symbol in parenthesis when the quantity is first introduced.

Table of Common Physical Quantities and their Typical Symbols

Quantity	Most Commonly Used Symbol
Time	t
Length/ width/ distance/ height/ radius	l/w/d/h/r
Speed	v
Acceleration	a
Angle	θ
Area	A
Volume	V
Mass	m
Density	ρ
Force	F
Torque	tau
Work	W
Mechanical Energy/ Internal Energy/Heat	E/U/Q
Power	P
Momentum	rho
Temperature	T
Entropy	S

Reinforcement Activity

Measure the distance from your knee to your heel. How far does your heel actually move when the angle of your knee joint goes from 0° (straight leg) to 90°?

CHAPTER 16.

BODY SURFACE AREA

Surface area (A) is an important feature of the human body. Surface area affects the rate at which heat transfers into or out of the body and the rate at which certain chemicals can be absorbed through the skin. The severity of burn injuries depends on the degree of the burn, but also on the percentage of total body surface area affected[1]. The areas and surface areas of geometric shapes can be found using various formulas, such as $1/2 \times base \times height$ for triangles. The surface area of a convoluted shape such as the human body is difficult to measure, but we can use typical *ratios* (proportions) to quickly approximate body surface area. For example the palm surface area can be easily measured as $length \times width$ and the ratio of palm surface area to body surface area is typically $1/200$, which might also be written as 1:200, 0.005, or 0.5%[2]. The units of area will

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[1] "Thermal Injuries" by Chemical Hazards Emergency Medical Management, U.S. Department of Health and Human Services

[2] "The surface area of the hand and the palm for estimating percentage of total body surface area: results of a meta-analysis." by Rhodes J, Clay C, Phillips M., U.S. National Library of Medicine, U.S. Department of Health and Human Services

be length units squared, such as square meters (meters squared or $\mathbf{m^2}$). We need to be careful when converting units involving powers (squared, cubed, etc.) and the chain-link method allows us to make sure our units cancel correctly.

Example square inches to square feet.

We are going to replace the carpet in a room. Carpet is sold by the square foot, so we are trying to determine the square footage of carpet in room. We use a measuring tape and find out that the room is 148 **in** long by 108 **in** wide. Multiplying length by width we get 15,984 $\mathbf{in^2}$. To convert to feet we need to multiply by the conversion factor *twice* in order to cancel the squared unit:

$$15,984\,\mathbf{in^2} = 15,984\,\cancel{in}\cdot\cancel{in}\left(\frac{1\,\mathbf{ft}}{12\,\cancel{in}}\right)\left(\frac{1\,\mathbf{ft}}{12\,\cancel{in}}\right)$$

Multiplying across the top and bottom we have:

$$15,984\,\mathbf{in^2} = 15,984\left(\frac{1\,\mathbf{ft^2}}{144}\right) = 111\,\mathbf{ft^2}$$

Reinforcement Activity

Measure your palm length and width in units of **cm**. Then calculate your palm surface area in units of $\mathbf{cm^2}$. Next, calculate your approximate body surface area in units of $\mathbf{cm^2}$**.** Finally use the chain-link method to convert your body surface area to both square inches (**in^2**) and **m^2**.

CHAPTER 17.

DOSAGE CALCULATIONS

Delivering medications is another critical function that Jolene performs many times on every shift and mistakes in dosage can have very serious consequences. Dosage calculations ensure patients receive the correct amount of each medication and Jolene uses the chain-link method of unit analysis to ensure that her patients receive correct dosages. “Three primary methods for calculation of medication dosages exist, and these include dimensional analysis, ratio proportion, and formula or desired-over-have method. Commonly used in solving chemistry and physics problems, dimensional analysis is fast becoming the go-to method for dosage calculations in nursing and the medical profession. Chances for error are diminished, thus increasing the popularity of these dosing calculations.”[1]

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[1] "Dose Calculation" by Tammy J. Toney-Butler and Lance Wilcox, National Library of Medicine, National Institutes of Health

Everyday Examples: Dosage Calculation

An MD orders 300 mg of Ibuprofen to be taken by a 6 kg infant every 4 hours. The label
shows 75 – 150 mg/kg per day max. Is the physician's order within normal range?

First let's calculate the max dosage for this infant:

$$150\,\mathbf{mg/kg/day} = \left(150\,\frac{\mathbf{mg}}{\cancel{\mathbf{kg}}\,day}\right)(6\,\cancel{\mathbf{kg}}) = 900\,\frac{\mathbf{mg}}{day}$$

Now let's calculate the ordered dose.

$$300\,\mathbf{mg}/(4\,\mathbf{hrs}) = \left(300\,\frac{\mathbf{mg}}{4\,\cancel{\mathbf{hrs}}}\right)\left(\frac{24\,\cancel{\mathbf{hrs}}}{1\,day}\right) = 1800\,\frac{\mathbf{mg}}{day}$$

The dosage is not within the normal range.

[2]

Exercises

You want to give 50 **mg/kg** of Fortaz to a child who weighs 25.5 **kg**. Fortaz is available in an oral suspension labeled 100 **mg/mL**. How many **mL** should be administered?

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[2] Adapted from "Medication Calculation Examination Study Guide " by Public Health Nursing, County of Los Angeles

CHAPTER 18.

UNIT 2 REVIEW

Key Terms and Concepts

Scientific Method/Process
Law
Principle
Theory
Empirical model
Physical (mechanistic) Model
SI measurement units
Unit conversion factor
Order of magnitude estimation
Scientific notation
Metric prefix

Unit 2 Learer Objectives [Corresponding Example Course Outcome #]

1. Describe the scientific method through an original example of how it could be applied to the student's everyday life. [5]
2. Identify the differences and relationships between empirical models, physical models, hypotheses, theories, and laws. [5]
3. Find necessary conversion factors and convert between SI and non-standard units for several physical quantities. [1]
4. Perform order of magnitude estimation. [2]

CHAPTER 19.

UNIT 2 PRACTICE AND ASSESSMENT

Outcome 1

1) What are the steps in the basic scientific method?

2) Use the summary of this 25-year, 7-country smoking and mortality study to identify the observation, question, hypothesis, test method, analysis method, reported uncertainty or confidence interval, and conclusions.

3) Explain how you could you apply the basic scientific method to a question from your everyday life. Be sure to identify how you would complete each step: observation, question, hypothesis, test method, analysis method, reported uncertainty or confidence interval, and conclusions.

4) How is the scientific method related to the modern scientific process?

Outcome 2

5) Provide an example of each of the following: empirical model, physical model, hypothesis, theory, and law. List any sources you used to find examples.

6) State which of the following categories the ideas

listed below fall under: empirical model, physical or mechanistic model, hypothesis, theory, or law. List any sources you used to help you decide.

- Foreign organisms were thought to be present inside tumors (microscopic studies never found evidence of this).
- Due to genetic instability, successive mutations, appearing in cells, lead to selection of cancer cells which feature specific phenotypic traits[1].
- Natural Selection
- All living organisms consist of membrane encased cells
- Plate Tectonics
- Statistical relationships are found between measured forest fire smoke exposure and other available air quality data. Those relationships are used to predict forest fire smoke exposure in geographic areas where it's not easily measured[2].

Outcome 3

7) What is the height in meters of a person who is 6 ft 1.0 **in**. tall? (Assume that 1 meter = 39.37 **in**.)

8) The speed of sound is measured to be 342 **m/s** on a certain day. What is this in km/h?

9) Soccer fields vary in size. A large soccer field is 115

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[1] "Evolving models of tumor origin and progression" by Iwona Mitrus, Ewa Bryndza, Aleksander Sochanik, and Stanisław Szala, U.S. National Library of Medicine, U.S. Department of Health and Human Services

[2] "An empirical model to estimate daily forest fire smoke exposure over a large geographic area using air quality, meteorological, and remote sensing data" by Jiayun Yao and Sarah B Henderson, Journal of Exposure Science and Environmental Epidemiology, Nature Research

m long and 85 **m** wide. What are its dimensions in feet + inches? (Assume that 1 meter equals 3.281 feet.)

10) Tectonic plates are large segments of the Earth's crust that move slowly. Suppose that one such plate has an average speed of 4.0 **cm**/year. (a) What distance does it move in 1 **s** at this speed? (b) What is its speed in kilometers per million years?

Outcome 4

11) Make an order of magnitude estimate of the number of cells in a hummingbird, assuming all the cells are the same size and approximating the the mass of an average cell to be ten times the mass of a bacterium. Be sure to cite your source for the size of a bacterium. (b) Making the same assumption, how many cells are there in a human?

(Exercises for outcomes 3 and 4 adapted from OpenStax College Physics [3]

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[3] OpenStax, College Physics. OpenStax CNX. Jul 16, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@11.35.

PART III.

UNIT 3: ERRORS IN BODY COMPOSITION MEASUREMENT

Learner Objectives

1. Compare and contrast precision, accuracy, systematic errors, and random errors. [4]
2. Identify sources of random and systematic errors.[4]
3. Explain how systematic and random errors affect precision, accuracy and uncertainty.[4]
4. Calculate and report uncertainties in measurements. [4]

CHAPTER 20.

BODY MASS INDEX

BODY COMPOSITION

Let's revisit Jolene, who works as a registered nurse (RN) on the medical/surgical (MED) floor of a large hospital. An important part of Jolene's job is patient education and on MED floor much of that education relates to healthy nutrition and body composition. Body composition attempts to quantify the relative amounts of different tissue types present in a person's body, typically with emphasis on ensuring a healthy amounts of fat relative to other tissues[1]. Body composition is just one of many measurable factors that health professionals use to evaluate a person's overall health and assess risk for type II diabetes, cardiovascular disease, sleep apnea, osteoarthritis, osteoporosis, and other medical conditions.

BODY MASS INDEX

The body mass index (BMI) attempts to categorize body

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1. "Measuring body composition." by J C K Wells and M S Fewtrell, U.S. National Library of Medicine, U.S. Department of Health and Human Services

composition using only height and weight as inputs. Health professionals like Jolene understand that the BMI can be useful when paired with other evaluations, but that it has many limitations when applied to individuals or very specific populations. For example, the extra weight caused by having more than average muscle can result in a false unhealthy weight categorization. [2]. Additional methods for determining body composition include bioelectric impedance, anthropometric, DEXA scan, hydrostatic weighing, and the skin fold method, which we will investigate in the following sections.[3]

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[2] "Assessing your weight and health risk" by National Heart, Lung, and Blood Institute, U.S. Department of Health and Human Services

[3] "The Math of Fitness" by Eric Kim, A Healthy U, Andrews University

CHAPTER 21.

THE SKINFOLD METHOD

THE SKINFOLD METHOD

The skinfold (caliper) method is one way to determine body composition. The skinfold method uses specially designed calipers to measure the thickness of skinfolds that are pinched from several specific locations on the body, as seen in this skinfold demonstration video[1].The skinfold thicknesses are correlated with body fat percentage using tables or equations that were produced by making both displacement and skinfold body composition measurements on many people[2].

[1] "3-Site Skinfold (Male)" by Sydney Richard, ptdirect

[2] "Taking Skinfold Measurements" by ptdirect

Personal-use grade skinfold caliper used for measuring skinfold thickness for body fat percentage calculation. Image Credit: Jks via Wikimedia Commons

The skinfold method is quick, easy, and requires minimal equipment, however there are many possible ways for error to enter the measurement. Analyzing the skinfold method will help us understand the concepts of error, precision, accuracy, and uncertainty, which actually apply to all measurements. Watching the short skinfold demonstration video will help you follow the discussion of these concepts.

SKINFOLD MEASUREMENT ERROR

Let's say a physical therapist (PT) measures a particular skinfold thickness one time. The result might not be very accurate, or close to the actual value, for a variety of reasons. For example, measuring above or below the center of the skinfold would produce a measurement error that would affect the accuracy of the results.

The PT could then make many measurements of each skinfold. If the collection of measurements were all relatively close together then the measurement would have high precision. On the other hand if the measurements were all relatively far apart then the measurement would have low precision. The measurement precision can be affected by the measurement method and/or by the equipment so improving the method or the equipment can improve precision. For example, the PT might draw a mark on the skin to be sure the measurement is made in the same place every time. A caliper with larger dial will make it easier to see which mark is closest to the needle position.

Low precision is not desirable, but it doesn't have to ruin the measurement accuracy if the error causing the lack of precision is a random error. For example, if the PT happens to randomly measure at various distances above or below the actual skinfold center in equal amounts then this error is random. In this case averaging all of the measurements should give a result that is relatively close to the actual value. *The effect of a random error on the accuracy can be reduced by averaging more measurements.*

Systematic errors cannot be reduced by averaging because they bias the result away from the actual value in the same direction every time. For example, if the PT made a mark on the skin to improve precision, but the mark was actually in the wrong spot, then every measurement would be inaccurate in the same way. In this case averaging the results would not produce an accurate result. Instead, systematic errors must be reduced by improving methods or equipment. For example, using the displacement method instead of calipers would improve the accuracy of the body fat percentage measurement. These issues are part of why the caliper method is slowly going out of favor for determining body fat percentage. Another reason is that this specific method might embarrass and/or lower a patient's motivation to visit with their health care provider about their health, and that negative outcome is not worth the body fat percentage information that might be gained from the measurement (precision is typically not better than 3% body fat anyway[3]).

To summarize: *Systematic errors reduce accuracy and increase discrepancy while random errors reduce precision and increase measurement uncertainty. Random errors also affect accuracy, but the effect can be reduced by averaging more measurements.*

Exercises

A stadiometer (center photograph) is used to measure stature (natural height of a person standing upright).

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[3] "Body Composition" by J. Andrew Doyle, Exercise and Physical Fitness Page, Georgia State University Department of Kinesilogy and Health

A stadiometer is used to measure the stature of a person. The person stands against the rod which is marked in 1 cm increments (usually). A movable headpiece is placed to just touch the top of the head and the headpiece indicator line shows the stature on the rod. Image Credit: "Home_Banner" by Indian Health Service, U.S. Department of Health and Human Services

[4]

An interactive or media element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bodyphysics/?p=291

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[4] "Height & Weight Measurement" by Indian Health Service, U.S. Department of Health and Human Services

CHAPTER 22.

PUPILLARY DISTANCE SELF-MEASUREMENT

You may have heard the old adage "*measure twice and cut once*". Scientists take this concept to the extreme, so the saying would be more like: "*measure 50 times, then calculate the average and determine the possible uncertainty. Next cut a cheap piece of cardboard to the average size and test to make sure that it fits first, then finally cut the board. After you put the board in place, evaluate the goodness of fit, then think about how you could get an even better fit next time. Oh yeah, and write everything down along the way so you or anyone else can come along and follow the same process every time.*" You might not make 50 measurements in your everyday life, but you can still use the concepts of error, precision, accuracy, and uncertainty to save yourself time, energy, and trouble.

Everyday Example

Tyler recently had an eye exam and his prescription changed. He has decided to order his new eyeglasses online to save money. He can upload a photo of his prescription, but he needs to provide his pupil distance, or PD and this is not written on the prescription. This is a common problem so the company website has a video explaining that PD is the distance between your pupils, measured in millimeters (**mm**) and showing how to measure PD using a ruler and a mirror.

Measuring pupil distance with a mirror. Image Credit: "Expert Reviewed How to Measure Your Interpupillary Distance" by WikiHow

[1]

Tyler tries the measurement and finds that the ruler is pretty far below his pupil and his pupil is several **mm** wide, so it's hard to line up the edge of the ruler with the center of one pupil and it's also hard to tell which mark on the ruler lines up best with the center of his other pupil. Even worse, his eye and the ruler both move a bit during the measurement. Tyler doesn't want to get his PD wrong and have to hassle with sending the glasses back.

Tyler makes several measurements and gets 56 **mm**, 57 **mm**, and 54 **mm** and he is uncertain of the actual value. He decides that because

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1. "Expert Reviewed How to Measure Your Interpupillary Distance" by WikiHow is licensed under CC BY-NC-SA 3.0

the marks on the ruler are plenty close together that piece of equipment isn't affecting his precision much. Instead, he decides his method is the culprit.

Tyler considers making a mark on his face just below one pupil that he can use to line up the edge of the ruler. After thinking more about it, Tyler realizes that if his mark wasn't perfect then this would introduce a systematic error into the measurement.

Instead, Tyler decides to ignore the precision issue and focus on getting an accurate result. He thinks it's likely that the difficulty in lining up the ruler makes his measurement sometimes too short and sometimes too long, so he decides to make a few more measurements and average all of the results. He makes four more measurements, getting 56 **mm**, 55 **mm**, 57 **mm** and 58 **mm**. Then he takes the average of all seven results:

$$Average\, PD = \frac{(56+57+54+56+55+57+58)\,\mathbf{mm}}{7} = 56.14\,\mathbf{mm}$$

The website for ordering glasses only let Tyler enter whole **mm** values, so he had to decide between 56 **mm** or 57 **mm**. Tyler's calculated average was closer to 56 **mm** so he entered that along with his prescription.

CHAPTER 23.

WORKING WITH UNCERTAINTIES

ERROR IN SCIENCE

The purpose of science is to discover new things, so we usually don't have an accepted answer to compare with the results of an experiment. Attempting to measure something that already has an accepted standard value before performing our experiment can expose systematic errors so that they can be fixed or taken into account. This is known as *calibration*. Evan after calibration we can't be certain that a systematic error has not affected our accuracy. "Students in science classes are in an artificial situation. Their experiments are necessarily repetitions of previous work, so the results are known. Because of this students learn a poor lesson about science. The good scientist [works hard to minimize possible sources of error and then] *assumes the experiment is not in error*. It is the only choice available. Later research, attempts by other scientists to repeat the result, will hopefully reveal any problems, but the first time around there is no such guide."[1] Bellevue College provides a more in-depth discussion of uncertainty and error.

UNCERTAINTY

Even assuming we have eliminated systematic errors from our measurement or experiment, the accuracy of our result could still be affected by random errors. Averaging many measurements reduces the effect of random error and analyzing the spread of those measurements allows us to define the measurement uncertainty. The *uncertainty of a measured value defines an interval that allows us to say with some defined level of confidence that a repetition of the measurement will produce a new result that lies within the interval.* Sometimes the uncertainty is determined primarily by the precision of an instrument, and sometimes other factors come into play.

Everyday Examples: Uncertainty in Tyler's Pupillary Distance Measurement

There are various statistical methods[2] to determine the uncertainty in Tyler's set of measurements, but we will just look at the range of values to get a quick idea of the precision in the measurement and use that for the uncertainty. We look at the seven values and the average and we notice that the values go up to 2 **mm** above the average and down to 2 **mm** below the average.

$$Average\ PD = \frac{(56+57+54+56+55+57+58)\ \mathbf{mm}}{7} = 56.14\,\mathbf{mm}$$

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1. "Accuracy vs. Precision, and Error vs. Uncertainty" by Physics Resources and References, Bellevue College
2. "Uncertainty in Measurement Results" by NIST Reference on Constants Units and Uncertainty, National Institute of Standards and Technology

We will use 2 **mm** as a rough estimate of the uncertainty. This method is the known as the *half-range method* because it uses half of the difference between the maximum and minimum measured values as the uncertainty. If we wanted to show the final result of Tyler's measurements including uncertainty in the standard way then we would write:

$$PD = 56\,\mathbf{mm} \pm 2\,\mathbf{mm}$$

To complete our uncertainty statement we need to provide some kind of confidence. We could say that *most of the time a new measurement will be within 2* ***mm*** *of the average.*

With only seven values it will be difficult to further quantify the uncertainty. A common rule of thumb that can be cautiously applied when we have taken many measurements is that *about 70* ***%*** *the time a new measurement will be less than 1/4 of the full range away from the average*. The full range in our example spans 4 **mm** so that would imply that roughly 70% of the time a new measurement will fall within 1 **mm** of the average. However, in our example we shouldn't really put a lot of weight into quoted percentage because have only seven measurements.

Examples: Rulers

What is the uncertainty in measuring the length of a piece of paper with a ruler?

The precision of a ruler typically determines the uncertainty in the measurement. If we have checked the length of the ruler against other standard rulers then we can assume it is accurate. A ruler with markings at a 1 **mm** interval will allow you to decide if the paper edge is closer to one mark or another. In other words, you will be able to tell if the paper edge is more or less than half-way between one mark and the next. We could then estimate the precision in the measurement to be half of one **mm** (0.5 **mm**) under ideal conditions because measurements would likely indicate the paper edge being closest to the same mark each time. To make a statement about our uncertainty we would then need a confidence level, in this case it would be qualitative: We *are very confident that repeated measurements will fall within 0.5* ***mm*** *above or below the average value.*

Getting a quantitative uncertainty typically requires statistical analysis of the measurement values. An example would be calculating the standard deviation and stating that *68 % of the time a repeated measurements will fall within one standard deviation from the mean).* Applying this type of statistical analysis requires making many repeated measurements and in this class we usually won't make enough so we need to just estimate our uncertainties.

Everyday Examples

What is the uncertainty in the mass measurement if you place a quarter on a standard electronic balance and obtain a reading of 6.72 **g**?

The scale is indicating the uncertainty in the measurement using the number of decimals it displays. The digits 6 and 7 are certain, and the 2 indicates that the mass of the quarter is likely between 6.71 and 6.73 grams. The quarter weighs *about* 6.72 grams, with a nominal uncertainty in the measurement of ± 0.01 gram. If the coin is weighed on a more sensitive balance, the mass might be 6.723 grams. This means its mass lies between 6.722 and 6.724 grams, an uncertainty of 0.001 gram. [3]

If wind currents in the room were causing the last digit to fluctuate between 6.77 grams and 5.67 grams then we would know the uncertainty was greater than the instrument precision. In that case we would have to average many values to ensure accuracy and then examine how those values were spread between 6.77 grams and 5.67 grams in order to determine the uncertainty.

Scientists try to reduce uncertainty as much as is practical and then use a variety of methods, some simple and some very sophisticated, to determine the size of the uncertainty for reported along with the results. In this textbook we will stick to the simple methods, but if you decide to continue studying science you will learn some of the more sophisticated methods[4][5].

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3. "Measurement Uncertainty, Accuracy, and Precision" by Paul Flowers, Klaus Theopold, Richard Langley, William R. Robinson, PhD, Chemistry 2e, OpenStax is licensed under CC BY 4.0.
4. "Uncertainty in Measurement Results" by NIST Reference on Constants Units and Uncertainty, National Institute of Standards and Technology
5. "Experimental Uncertainty" by EngineerItProgram, California State University, Chio

Reinforcement Exercises

SIGNIFICANT FIGURES

Notice that in the previous example we have rounded the result to drop the decimal places from his result. This is because it would be meaningless to include decimals in the hundredth of a **mm** place if we don't even know the answer to within 2 **mm**, which is in the one **mm** place. Dropping the decimal places changes the number of significant figures in our result match our uncertainty. *The significant figures in a result are those digits that contribute to showing how precisely we know the result.*

Special consideration is given to zeros when counting significant figures. The zeros in 0.053 are not significant,

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because they are only placeholders that locate the decimal point. There are two significant figures in 0.053. The zeros in 10.053 are not placeholders but are significant—this number has five significant figures. The zeros in 1300 may or may not be significant depending on the style of writing numbers. They could mean the number is known to the last digit, or they could be placeholders. So 1300 could have two, three, or four significant figures. Typically when you see a value like 1300 meters the zeros don't count, but we can avoid ambiguity by using scientific notation and writing 1.3×10^3 meters or using a metric prefix and writing 1.3 kilometers[6]. The table below will help you deal with zeros.

Significant Figure Examples

Result	Number of Placeholder Zeros	Number of Significant Figures
300.0	0	4
0.0003	4	1
0.000300	1 (first one)	6
300.07	0	5
300.0700	0	7
375	0	3
3,750,000	3 (typically)	3 (typically)
3.75×10^3	0	3

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[6] OpenStax, College Physics. OpenStax CNX. Jul 6, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@11.20.

Reinforcement Activity

Determine how many significant figures are in each of these reported results:

- $517\,\mathbf{m}$
- $0.00180\,\mathbf{mi}$
- $6701\,\mathbf{s}$

Reinforcement Activity

Use the reported uncertainties to adjust each of the following results to the correct number of significant figures:

- $(517 \pm 20)\,\mathbf{m}$
- $(0.00180 \pm 0.001)\,\mathbf{mi}$
- $(6701 \pm 2)\,\mathbf{s}$

METHOD OF SIGNIFICANT FIGURES

Sometimes values are reported without uncertainty, but

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the level of uncertainty is still implied by the number of significant figures. When we express measured values, we can only list as many digits as we initially measured with our measuring tool. Tyler reported his first PD measurement as 56 mm, but he could not express this value as 56.31 mm because his measuring tool lacked the precision to measure down to the hundredth of a millimeter. Tyler had to decide which millimeter marking lined up with his pupil so the 1 mm digit hasuncertainty. The last digit in a measured value has always been estimated in some way by the person performing the measurement. Using the method of significant figures, *the last digit written down in a measurement is the first digit with some uncertainty.* [7] In this way significant figures indicate the precision of a measuring tool that was used to measure a value.

Whether uncertainties are written out or implied, we still need to account for the fact that measured values have uncertainty when we use those values in calculations. We will use four general rules to determine the number significant figures in our final answers.

- 1) For multiplication and division, the result should

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[7] OpenStax, College Physics. OpenStax CNX. Jul 6, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@11.20.

have the same number of significant figures as the least number of significant figures in any of the values being multiplied or divided.

- 2) For addition and subtraction, the result should have the same number of decimal places as the least number of decimals in any of the values being added or subtracted.
- 3) Counting discrete objects may have zero uncertainty. For example, sitting at a table with three oranges on it, you can measure the number of oranges on the table to be 3 with full certainty.
- 4) Definitions can have zero uncertainty. For example, the definition of a kilometer is 100 meters, so if using this conversion factor in a calculation it does not contribute to adjusting your significant figures.

Everyday Examples

Each of Tyler's PD measurements are reported to the one's place due to his rulers' precision. He took the average to get the final result:

$$Average\ PD = \frac{(56+57+54+56+55+57+58)\,\mathbf{mm}}{7} = 56.14\,\mathbf{mm}$$

We see that to take the average Tyler had to add up the values:

$$(56+57+54+56+55+57+58)\,\mathbf{mm}=393\,\mathbf{mm}$$

Applying the rule for addition (rule # 2), the result must have its last digit in the ones place because that was the least number of decimals in any number we used.

Tyler then divided by the number seven to get the average, but because this is just a count of how many measurements we made it has no uncertainty and doesn't affect the significant figures. So applying the rule for division, the final result should have the same number of significant figures as the least number in the division, which in this case is the three significant figures in 393 **mm**. Therefore our final result would be 56.1 **mm**, which implies that we certain of the 56, but we aren't sure about the 0.1 because have uncertainty in the tenth of a millimeter place. This result has more significant figures than were produced simply looking at the range of values to roughly estimate the uncertainty; but remember we expected that quick method to be an overestimate of uncertainty so this result makes sense.

Reinforcement Exercises

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CHAPTER 24.

OTHER METHODS OF REPORTING UNCERTAINTY*

Sometimes scientists report uncertainty as percentages of the result. For Tyler's example we would divide the uncertainty by the result and the multiply by 100 to find the percent uncertainty before writing it behind the result:

$$PD = 56\,\mathbf{mm} \pm \left(\frac{2\,\mathbf{mm}}{56\,\mathbf{mm}}\right) \times 100 = 56\,\mathbf{mm} \pm 4\%$$

Finding percent uncertainty is an important step in some of the more sophisticated methods of determining the total uncertainty in the result of a calculation that uses several numbers that each have uncertainties themselves. This text won't get into those sophisticated methods, but if you are curious you can read about some of them in Section 1.3 of OpenStax College Physics.

In addition to the methods we just discussed, Scientists sometimes report uncertainty in other ways, such as confidence intervals. Typically this method states 95% confidence that an actual value lies within the interval between two values. For example, this 25-year and 7-country study on cigarette smoking and mortality risk found that the hazard risk for all causes of death was 1.3x higher for smokers than non-smokers with a 95% confidence that the value was between 1.2x and 1.4x. (The risk was 1.8x higher for smokers of more than 10 cigarettes a day and even higher for death caused by coronary heart disease, all stroke, other arterial disease, lung cancer, other cancer, chronic obstructive pulmonary disease, and other disease in smokers[1].

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[1] "Cigarette smoking and mortality risk: twenty-five-year follow-up of the Seven Countries Study" by Jacobs DR Jr, Adachi H, Mulder I, Kromhout D, Menotti A, Nissinen A, Blackburn H., U.S. National Library of Medicine, U.S. Department of Heath and Human Services

CHAPTER 25.

UNIT 3 REVIEW

Key Takeaways

Measurement error

Random error

Systematic error

Precision

Accuracy

Uncertainty

Significant figures

Learner Objectives

1. Compare and contrast precision, accuracy, systematic errors, and random errors. [4]
2. Identify sources of random and systematic errors.[4]
3. Explain how systematic and random errors affect precision, accuracy and uncertainty.[4]

4. Calculate and report uncertainties in measurements. [4]

CHAPTER 26.

UNIT 3 PRACTICE AND ASSESSMENT

Outcomes 1, 2, 3

1. Would putting larger tires on a vehicle introduce random or systematic error into the speedometer reading? Would this affect the accuracy or precision (or both) of the speedometer? Explain your answers.

2. Would a wiggling baby introduce random or systematic error into a measurement of its weight? Would this affect the accuracy or precision (or both) of the weight measurement? Explain your answers.

3. Would slightly under-filling measuring cups to prevent spilling ingredients introduce random or systematic error into the measurement of ingredient volumes? Would this affect the accuracy or precision (or both) of the measurement volumes. Explain your answers.

A set of measurements of a physical quantity was made for comparison to an accepted standard value. The data were plotted in graphs with the measured values on the horizontal axis and the number of times each value occurred on the vertical axis. This type of graph is known as a histogram and the data on the vertical axis are called the frequencies. Use the histograms below to answer the questions that follow.

Histograms of values measured during an experiment.

4. For each histogram state whether the data suggest the measurements were relatively accurate, precise, both, or neither. Explain your reasoning.
5. For each histogram state what types of errors were likely to be relatively significant: random, systematic, both or neither. Explain your reasoning.

Outcome 4

6)A person measures his or her heart rate by counting the number of beats in 30 **s** as timed using a clock on the wall, such as the one in the image below. They start counting when the second hand jumps onto a particular tick mark (say the 12) and then stop counting when it jumps to the opposite mark (say the 6). A reasonable estimate of the uncertainty in the time measurement would be which of the values listed below? Explain your reasoning.

a) 0.05 **s**
b) 0.5 **s**
c) 5 **s**
d) 50 **s**

Typical wall clock with hour, minute, second hands and 1 hour, 1 min (1s) divisions. Image Credit: Clock by Lee Haywood via Wikimedia Commons

1

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1. Clock By Lee Haywood from Wollaton, Nottingham, England (Clock) [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons

7. Estimate the uncertainty in counting the beats in the previous problem. Explain your reasoning.

*8) If 47 beats were counted by the person in the previous problem, what a was their heart rate in BPM in correct significant figures. Indicate the total % uncertainty and total uncertainty.

PART IV.

UNIT 4: BETTER BODY COMPOSITION MEASUREMENT

Learner Objectives

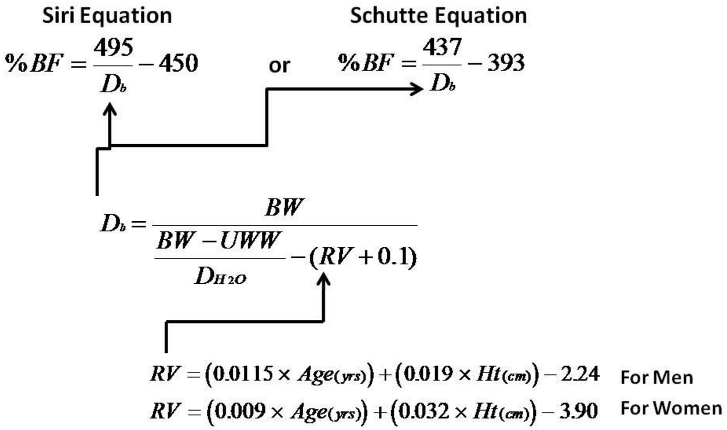
1. Compare and contrast: mass, volume, density, weight and apparent weight and explain how each are measured.[2]
2. Apply the concept of static equilibrium to determine the magnitude and direction of unknown forces.[3]
3. Apply Archimedes' principle and density concepts to predict if objects will sink or float.[2]
4. Determine density by hydrostatic weighing and from mass and volume measurements.[4]

CHAPTER 27.

BODY DENSITY

BODY FAT PERCENTAGE FROM BODY DENSITY

Health care professionals like our RN friend Jolene understand that BMI provides a relatively quick way to asses body composition and gives providers and patients an easy method for monitoring changes, but it does not always accurately capture a person's body composition. The errors common to the previously discussed skinfold method and the BMI can be somewhat avoided by actually measuring body density, which can then be used in empirical formulas that interpolate body fat percentage from body density:



Formulas used in calculating residual lung volume, body density, and body fat percentage. Image Credit: Measure Body Fat Via Under Water Weighing by MattVerlinich via Instructables

[1]

Your lab for this unit might involve some of these formulas and if you are curious you can read more about those formulas, play with a simulation of hydrostatic weighing, check out a website that does the calculations for you, and see that different formulas have been developed for different population sets in an effort to increase accuracy.[2]. Determining body fat percentage from body density is not something that Jolene would do on the MED floor, but athletic training facilities and

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1. "Measure Body Fat via Under Water Weighing" by Matt Verlinich, Instructables, Autodesk
2. "Under Water Weighing" by University of Vermont College of Medicine, Department of Nutrition and Food Science,

clinics specializing in care associated with body composition might use this method.

BODY DENSITY

MASS AND VOLUME

In order to understand density and how it might be measured, we need to know that volume (V) is the amount of space taken up by an object. Mass (m) is a measure how strongly an object attracts other objects by gravitation and resists changes in its motion. Atoms are the matter that make up everyday objects like the body, and each type of atom exhibits a certain mass, so we sometimes speak of the mass as a measure of the amount of matter in the object. For example, 6.022×10^{23} carbon atoms will exhibit a mass of 12.011 grams. The number at the bottom of each square in the periodic table tells you the mass (in grams) exhibited by 6.022×10^{23} of that type of atom. This seemingly odd number is known as *Avogadro's Number*.

DENSITY

The SI units for volume and mass are cubic meters (**m^3**) and kilograms (**kg**). Mass Density (ϱ), which we usually shorten to just density, for any object is defined as its mass divided by its volume. The same mass of different materials will have different volume, and thus different densities. For example 1 **kg** of foam takes up much more space than 1 **kg** of steel (in fact, about 80 times more). This giant table of material densities is a useful reference (click the ***kg/m^3*** *button* to see the values in SI units).

Reinforcement Exercises

Sometimes weight density is used instead of mass density, in which case weight (pull of gravity on an object) rather than mass is divided by the object volume. The following chapters will explain how we measure the volume, weight, and mass of a body in order to calculate body density for use in determining body composition.

Reinforcement Exercises

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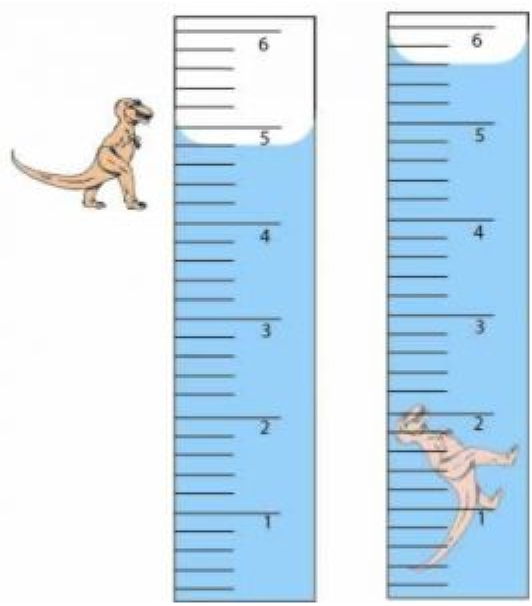
CHAPTER 28.

BODY VOLUME BY DISPLACEMENT

VOLUME BY DISPLACEMENT

The displacement method (submersion, or dunking method) can be used to accurately measure the volume of the human body and other oddly shaped objects by measuring the volume of fluid displaced when the object is submerged, as illustrated in the figure below.



When the dinosaur is submerged some of the water is displaced and the water level rises. The displaced volume is measured by reading the gradings, in this case 49 to 53, for a total of 4 volume units (which could be $\mathbf{cm}^3$ *for a toy dinosaur or* $\mathbf{m}^3$ *for a real one). Image credit: Greg Golz, Exploring Science*

[1]

BODY VOLUME

Measuring body volume with the displacement method requires specialized equipment, such as a large tub of water with volume grading (markings) or a special scale that can measure the apparent weight of a submerged

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1. "Density Using Displacement" by Greg Golz, https://sites.google.com/site/sciencegolz/ is licensed under CC BY 4.0

person. Recently technologies have been developed that allow for air rather than water to be used as the submersion fluid, opening up the method to a broader set of the population [2]

"Infant body composition through air displacement plethysmography" by Cosmed via Wikimedia Commons

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[2] "Bod Pod Services" by Oregon Clinical & Translational Research Institute, Oregon Health Sciences University.

[3] By Cosmed [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)], from Wikimedia Commons

CHAPTER 29.

BODY WEIGHT

WEIGHT AS A FORCE

Now that we know how to find the volume of a body, we just need to measure body mass in order to find body density. We typically measure the mass of a body by first measuring the weight using a scale, and then calculating mass from the measured weight. Weight is just another name for the force of gravity on an object. In everyday experience, a force (*F*) is any push or pull on an object. Forces can move objects, deform objects, or both. Often *W* is used to abbreviate weight, but F_g is also used because it reminds us that an object's weight and the force of gravity on the object are the same thing. Throughout this book we will learn about other forces, including buoyant force, tension, normal force, friction, and air resistance. We typically represent forces with arrows that point in the direction the force pushes (or pulls). We usually try to make the length of the arrows proportional to how big the forces are, in which case the arrows can be called vectors. The SI unit for weight, and all other forces, is the Newton(**N**). In the U.S. we often use pounds (**lbs**) instead of Newtons as our unit of force. One pound is equal to 4.45 Newtons.

Reinforcement Exercises

Reinforcement Activity: Free Body Diagrams

Draw a stick figure of a person jumping on a trampoline. Then add an arrow representing gravity acting on you while they are in the air. The arrow should start at the center of the person and point in the direction that gravity acting. Label the force arrow.

Draw a second figure that is just standing on the trampoline and add arrows to represent the forces acting on the person. Label the forces. [Hint: There are two forces.]

Do you think the lengths of the two force vectors should be the same or different? Explain your thought process.

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FREE BODY DIAGRAMS

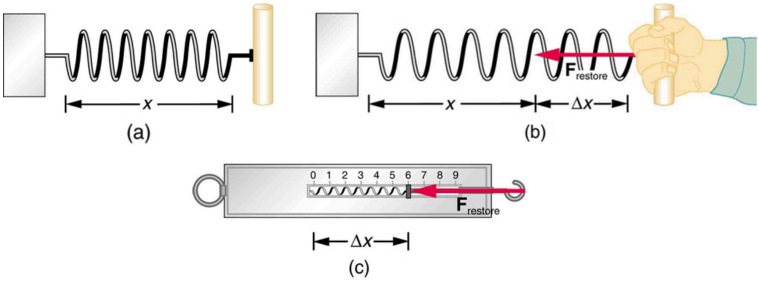
A diagram, such as you have drawn above, that represents an object in a simplified way and shows the forces acting on it using vectors is known as a free body diagram. We often make the diagrams very simple and represent the object with just a dot, so that the force vectors are easier to see.

CHAPTER 30.

MEASURING BODY WEIGHT

SPRINGS

The predictable and repeatable way in which springs stretch in response to applied forces provides a method for measuring weight and other forces. Furthermore, springs can be designed to produce conveniently measurable stretch distances for a wide variety of forces. For example, if you were pull on each end of a steel wire that had the same diameter as a human hair, you would not be able to noticeably stretch the wire. However, if that rod were formed into a spring, then you could stretch the spring with your bare hands.



The force exerted on a stretched spring determines how far it stretches. (a) This spring has a length x when not stretched. (b) The resistance of the spring to deformation causes a force, $F_{restore}$ to be exerted back on whatever is pulling on the hook. (c) A spring scale is one device that uses a spring to measure force. Image Credit: OpenStax University Physics

[1]

Springs follow Hooke's Law which states that the restoring force, F_R exerted by the spring is equal to the stretch or compression distance, known as the displacement (Δx), multiplied by spring stiffness (k) and the direction of the force is opposite to the direction of the displacement.

(1) $\mathbf{F_R} = -k\boldsymbol{\Delta}\mathbf{x}$

A higher spring stiffness means the spring shows a greater resistance to stretching or compressing. Spring stiffness is often called the spring constant. The negative sign tells us that the restoring force provided by the spring always points in the opposite direction as the displacement.

Check out this simulation of Hooke's Law:

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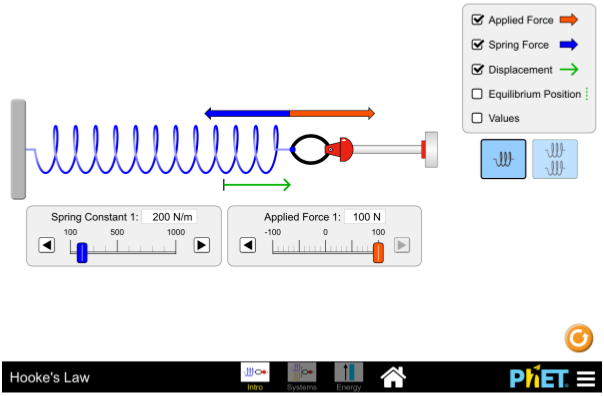
1. OpenStax University Physics, University Physics Volume 1. OpenStax CNX. Sep 14, 2018 http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@11.28.



☑ Applied Force
☑ Spring Force
☑ Displacement
☐ Equilibrium Position
☐ Values

Spring Constant 1: 200 N/m

Applied Force 1: 100 N

Reinforcement Activity

VECTORS

As we analyze forces we are beginning to see that it's very important to keep track of their directions in order to know if they are cancelling out or adding together, which is why we represent them with vectors. As we move through the textbook we will encounter a few other quantities that are also vectors and we will need to remember which quantities require keeping track of their direction (vectors) and which don't (scalars). For example,

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the displacement of the spring is vector because is has a size that tells us how far it was displaced, and a direction that tells whether it was stretched or compressed that distance. We will make the symbols for vectors **bold** when writing equations. We should be able to avoid confusion with our **bold** units by only writing units behind numeric values and not behind symbols. You may have noticed that already started using this **bold** convention in the equation for the spring above. In some cases we might only be interested the size of a vector, called the magnitude, and then we will not make it bold.

WEIGHT WITH A SPRING SCALE

Spring scales are designed to take advantage of Hooke's law to determine the size of the force stretching the spring by measuring the displacement. For example when hanging the object from the spring scale the force of gravity will pull it down and the restoring force in the spring pulls it up, as represented by the free body diagram of the turtle in the following image:

Biologist Dr. Paula Khan holds still and keeps the scale vertical while she weighs a desert tortoise before release as part of the Fort Irwin, Calif., tortoise translocation. Photo Credit: "Paula Khan" by Neal Snyder via Wikimedia Commons

[2]

When weighing an object that is not in motion we know the restoring force from the spring must perfectly balance the weight because the object remains still, which is a state known as static equilibrium. In fact, *anytime an object is at rest (a.k.a static) then all of the forces on the object must be perfectly balanced out, (a.k.a equilibrium)*. Therefore,

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[2] "Paula Khan" by Neal Snyder via Wikimedia Commons released in the public domain by U.S. Army Environmental Command

if we are careful to make sure the object remains still we can measure the weight by finding the restoring force from the spring, which is determined by the displacement. Typically spring scales will have markings on them which indicate the restoring force for each stretch distance, so we don't have to actually calculate the restoring force from the displacement every time we use the scale.

Many analog scales are based on multiple springs or the resistance to deformation by objects other than springs, but they still determine weight using measurement of a deformation combined with a known relation between deformation and force and an assumption of static equilibrium.

Reinforcement Exercises

DIGITAL SCALES

Many modern scales follow the same principle as spring scales, but instead of measuring the deformation directly, they measure an electric voltage created by a material in response to being deformed. Materials that produce

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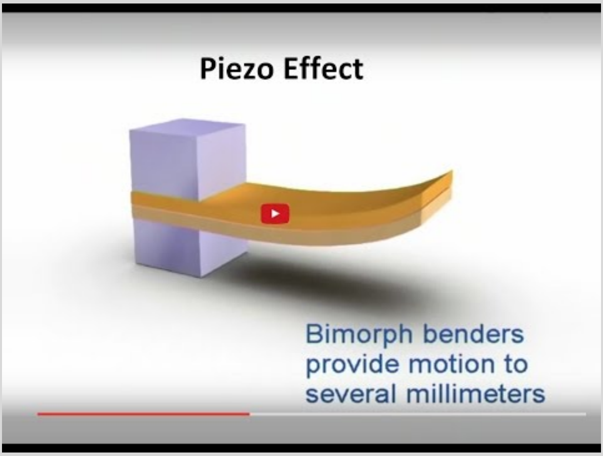
voltages in response to deformation are known as piezoelectrics. As long as the relations between voltage and deformation and between deformation and applied force are both known, the scale can determine your weight by measuring a voltage.

An interesting aspect of the piezoelectric effect is reversibility, meaning that piezoelectric materials not only produce a voltage in response to deformation, they will also deform in response to an applied voltage, which allows for piezoelectric motors.



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CHAPTER 31.

BODY DENSITY FROM DISPLACEMENT AND WEIGHT

MASS FROM WEIGHT

Scales measure weight, but to calculate body density we need mass. Some scales read off mass, such as the electronic scale in the image below, even though they actually measure weight as discussed in the previous chapter.

A food product sits on a digital weighing scale with options for displaying weight in pounds or mass in kilograms or grams. The readout is 243 g. Image Credit: "Digi-keukenweegschaal1284" by Algont via wikimedia commons.

[1]

Mass can be determined from a weight because weight is just the force of gravity on the body and force of gravity depends on mass in a known way. On the surface of the Earth, the force gravity on an object is related to its mass by the equation:

(1)

$$Force\,of\,gravity = mass\ \times\ acceleration\,due\,to\,gravity\,)$$

The acceleration due to gravity on Earth, typically abbreviated to *g*, has a value of 9.8 $\mathbf{m/s^2}$ and doesn't

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1. "Digi-keukenweegschaal1284" by Algont [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/)] via wikimedia commons.

change much over the entire surface of the Earth. Therefore we (and scales) can measure weight and then use equation (1) above to calculate mass. Understanding why the constant g is called the *acceleration due to gravity* requires introducing acceleration, which we will do in a later unit, so for now we recognize it as a constant value that relates mass and weight for objects on the surface of Earth.

Force is a vector, so we need to specify a direction for the gravitational force, which is always down toward Earth's center. We can summarize the previous equation in symbol form:

(2) $\mathbf{F} = mg \;\; (downward)$

Reinforcement Exercises: Helen Maroulis

You can read more about Helen Maroulis here

CALCULATING BODY DENSITY

We now know how to measure volume by displacement and how to determine mass from a weight measurement so we should be able to determine body density. First we measure the weight, then calculate the mass. Dividing

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the mass by the volume found from our displacement measurement will give us the body density. Give it a try:

Reinforcement Exercises: Body Density

BODY WEIGHT AND MASS ON THE MOON

The value of g only holds constant near the surface of the Earth, and therefore scales that use equation (1) to calculate mass from measured weight will read incorrect results. For example, your mass doesn't change just because you go to the moon (there isn't suddenly less matter inside you), but your weight does change. In fact if you stood on a scale on the moon it would measure a weight about 1/6 of what it would read on Earth. The scale wouldn't know you were on the moon instead of the Earth, so if the scale then tried to calculate your mass from weight, it would read a mass that is 1/6 the actual value. Of course you didn't lose 5/6 of yourself on the way there, so that would not be correct.

UNIVERSAL LAW OF GRAVITATION*

When you do want to calculate the force of gravity and

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you are not near the surface of the Earth then use the Universal Law of Gravitation.

The Universal Law of Gravitation states that the gravitational force between two objects depends on the mass of each object (m_1 and m_2) and the distance between their centers, (r). To calculate the gravitational force we need to multiply the two masses together, divide by the distance between them squared, and finally multiply by the universal gravitational constant G, which always has the same value of $6.67408 \times 10^{-11} \frac{\mathbf{m^3}}{\mathbf{kg^1 s^2}}$. Written in equation form the universal law of gravitation is:

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(3) $\mathrm{F}_g = G\frac{m_1 m_2}{r^2}$

Reinforcement Exercise

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CHAPTER 32.

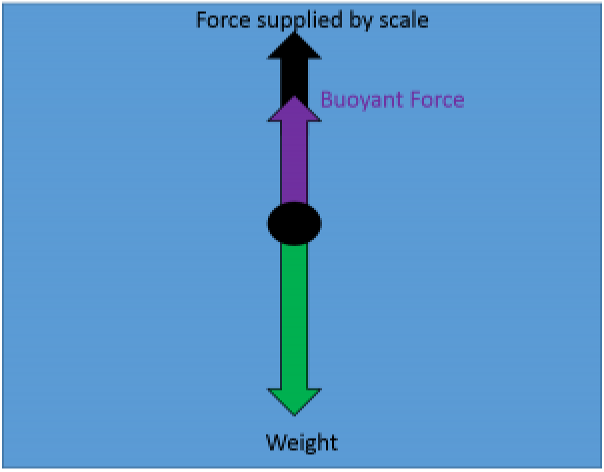
UNDER WATER WEIGHT

APPARENT WEIGHT

When an object is held still under water it *appears* to weigh less than it does in air because the buoyant force is helping to hold it up (balance its weight). For this reason, the reduced force you need to apply to hold the object is known as the apparent weight. When a scale is used to weigh an object submerged in water the scale will read the apparent weight. When performing hydrostatic weighing for body composition measurement the apparent weight is often called the under water weight (UWW).

STATIC EQUILIBRIUM

When weighing under water we know the buoyant force must be equal to the difference between the weight and apparent weight because the object remains still, which is a state known as static equilibrium. For an object to be in static equilibrium, all of the forces on it must be balanced so that there is no net force. For the case of under water weighing, the buoyant force plus the force provided by the scale must perfectly balance the weight of the object, as long as the object is holding still. We can use arrows to represent the forces on an object and visualize how they are balanced or unbalanced. This type of diagram is known as a free body diagram (FBD). The direction of arrows shows the direction of the forces and the arrow lengths shows the size (magnitude) of the force. In this case we call the arrows vectors and say the forces they represent are vector quantities. The FBD for a person undergoing hydrostatic weighing would look like this:



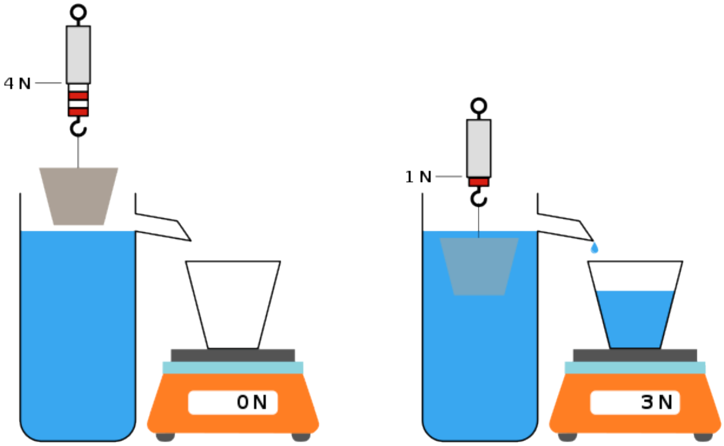
Free body diagram of an object hanging from a scale, submerged in water. The length of the weight arrow is equal to the combined lengths of the force supplied by the scale and the buoyant force. A scale will read the weight that it must supply, therefore it will read an apparent weight for submerged objects that is less than the actual weight.

We learned in the last chapter that scales measure the force that they are supplying to other objects. The scale must supply less restoring force to counteract weight and maintain static equilibrium when the buoyant force is also helping, therefore the scale will provide a apparent weight reading that is less than the actual weight.

ARCHIMEDES' PRINCIPLE

Measuring the weight and apparent weight of a body allows us to calculate its density because the buoyant force that causes the reduction in apparent weight has a special relation to the amount of water being displaced by the body. Archimedes' Principle states that *the buoyant force provided by a fluid is equal to the weight of the fluid displaced*.

Reinforcement Exercises



Demonstration of Archimedes' Principle. The buoyant force is equal to the weight of the water displaced, which in this case is 3 **N***. The buoyant force cancels out 3* **N** *worth of the objects weight, so the scale only pulls up with 1* **N** *to hold the object in static equilibrium. As a result, the scale reads an apparent weight of only 1* **N***. Image Credit: "Archimedes-principle" by MikeRun via Wikimedia Commons*

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[1]

BUOYANT FORCE AND DENSITY

A given mass of low density tissue will take up volume relative to the same mass of high density tissue. Taking up the volume means more water is displaced when the body is submerged so the buoyant force will be larger compared to the weight than it would be for a more dense body. In turn, that means that apparent weight is smaller relative to actual weight for bodies of higher density. By comparing weight and apparent weight, the body density can be determined. We will do that in the next chapter, but first we should become more familiar with the Buoyant force.

Everyday Example

The water displaced by a brick weighs less than the brick so the buoyant force cannot cancel out the weight of the brick and it will tend to sink (left diagram). To hold the brick in place you must provide the remaining upward force to balance the weight and maintain static equilibrium. That force is less than the weight in air so the brick *appears* to weigh less in the water (right diagram).

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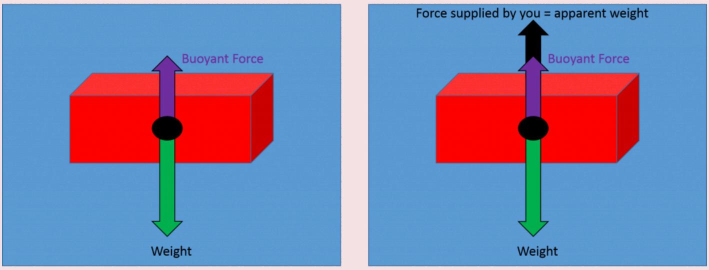
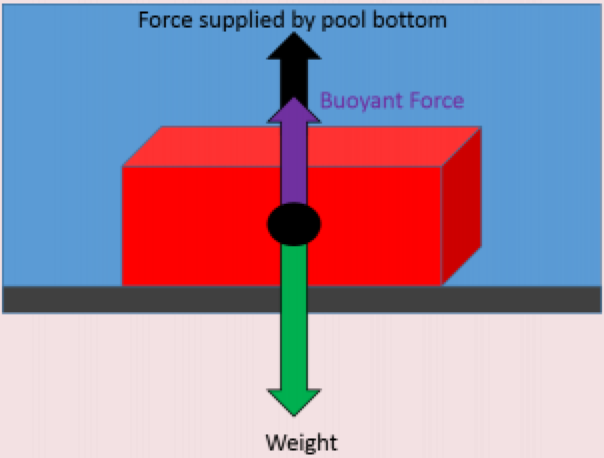
1. "Archimedes-principle"By MikeRun [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], from Wikimedia Commons



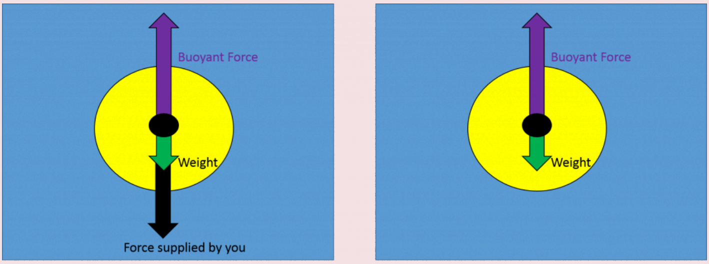
Free body diagrams for bricks in water. The brick on the left is sinking, the brick on the right is being held in place by you.

If you let go of the brick it will be out of equilibrium and sink to the pool bottom. At that point the pool bottom is providing the extra upward force to balance out the weight, and the brick is once again in static equilibrium.



Free body diagram of a brick sitting on the bottom of a pool.

The water displaced by an entire beach ball weighs more than a beach ball, so if you hold one under water the buoyant force will be greater than the weight. Your hand is providing the extra downward force to balance out the forces and maintain static equilibrium (left diagram). When you let go, the forces will be unbalanced and the ball will begin moving upward (right diagram).



Free body diagrams of a beach ball under water. The ball on the left is held in place by you. The ball on the right will float upwards.

The density of ice is only about 9/10 that of water. The weight of the water displaced by only 9/10 of the iceberg has the same weight as the entire iceberg. Therefore, 1/10 of the iceberg must remain exposed in order for the weight and buoyant forces to be balanced and the iceberg to be in static equilibrium.

An iceberg floating with roughly 9/10 of its volume submerged. Image Credit: "Iceberg" created by Uwe Kils (iceberg) and User:Wiska Bodo (sky) via Wikimedia Commons

[2]

Reinforcement Exercises

Check out this buoyancy simulation which lets you control how much objects of different masses are

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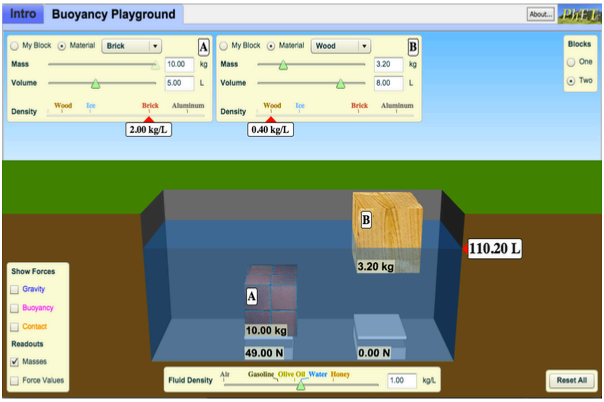
[2] "Iceberg" created by Uwe Kils (iceberg) and User:Wiska Bodo (sky). [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons

submerged and shows you the resulting buoyant force along with forces provided by you and a scale at the bottom of the pool (apparent weight).



○ My Block ● Material Brick
Mass 10.00 kg
Volume 5.00 L
2.00 kg/L

○ My Block ● Material Wood
Mass 3.20 kg
Volume 8.00 L
0.40 kg/L

Fluid Density 1.00 kg/L

Not-So-Everyday Example

Submarines control how much water they displace by pumping water in and out of tanks within the submarine. When water is pumped inside, then that water is not displaced by the sub and it doesn't count toward increasing the buoyant force. Conversely, when water is pumped out that water is now displaced by the sub and the buoyant

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force increases, which is the concept behind the maneuver in the following video:

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CHAPTER 33.

HYDROSTATIC WEIGHING

The method of hydrostatic weighing allows us to determine the average density (ρ) of a any object without any need for a volume (V) measurement by measuring only its weight (W_0) and apparent weight, also known as under water weight (UWW). To see how we arrive at this useful result, follow the steps in the derivation at the end of this chapter.

(1) $$\rho = \frac{W_O}{W_O - F_A}\rho_W$$

Reinforcement Exercises

The previous equation is very similar to the body density equation used for hydrostatic weighing, but you will notice a slight difference. The previous equation determines the average density of the object including any hollow parts containing trapped air, but the body density equation is designed to determine the average density of body tissues only, not including trapped air. Therefore, the body density equation is modified to account for a volume of air trapped inside the body, known as the residual volume (RV). Also different standard symbols are used to designate body density, apparent weight, and water density.

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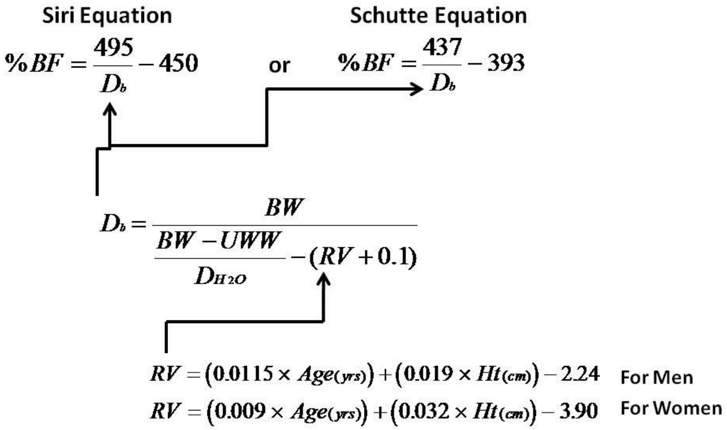

$$\%BF = \frac{495}{D_b} - 450 \qquad \%BF = \frac{437}{D_b} - 393$$

$$D_b = \frac{BW}{\frac{BW - UWW}{D_{H2O}} - (RV + 0.1)}$$

$$RV = (0.0115 \times Age_{(yrs)}) + (0.019 \times Ht_{(cm)}) - 2.24$$

$$RV = (0.009 \times Age_{(yrs)}) + (0.032 \times Ht_{(cm)}) - 3.90$$

Formulas used in calculating residual lung volume, body density, and body fat percentage. Image Credit: Measure Body Fat Via Under Water Weighing by MattVerlinich via Instructables

[1]

SPECIFIC GRAVITY

The ratio of the density of a substance to that of water is known as the specific gravity. Specific gravity can be determined by hydrostatic weighing. If we simply divide both sides of our density equation by the density of water we will have a formula for the specific gravity with weight and apparent weight as input:

$$SG = \frac{\rho}{\rho_W} = \frac{W_O}{W_O - F_A} \qquad (2)$$

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1. "Measure Body Fat via Under Water Weighing" by Matt Verlinich, Instructables, Autodesk

Reinforcement Exercises

HYDROSTATIC WEIGHING EQUATION DERIVATION

We arrived at equation (1) by starting with the definition of density as mass divided by its volume:

$$\rho = \frac{m_O}{V_O}$$

We can find the mass of an object if we divide its weight by *g:*

$$m = \frac{W_O}{g}$$

Inserting that result for mass into the density equation we have:

$$\rho = \frac{W_O}{gV_O}$$

For a completely submerged object the volume of water displaced is equal to the volume of the object, so we can replace V_O with V_D.

$$\rho = \frac{W_O}{gV_D}$$

Using the definition of density again, we can replace

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the volume of water displaced with the displaced water mass (m_W) divided by water density (ρ_W).

$$\rho = \frac{W_O}{g(m_D/\rho_W)} = \frac{W_O}{gm_D}\rho_W$$

We can look up the density of water, but it depends on the water temperature, which is why its important to measure the water temperature when hydrostatic weighing. Notice that we happen to have the mass of displaced water multiplied by **g** in the previous equation. That is exactly how we calculate the weight of the displaced water (W_D), so we can make that substitution:

$$\rho = \frac{W_O}{W_D}\rho_W$$

Archimedes' Principle which tells us that the *buoyant force pushing upward on objects in a fluid is equal to the weight displaced fluid.* Therefore we can replace W_D with F_B.

$$\rho = \frac{W_O}{F_B}\rho_W$$

We have learned that the difference between an object's weight (W_0) and apparent weight (W_A) tells us the size of the buoyant force (F_B), as long as the body is in static equilibrium (holding still):

$$F_B = W_O - F_A$$

Making that replacement in our density equation we have:

$$\rho = \frac{W_O}{W_O - F_A}\rho_W$$

We now have an equation that allows us to calculate the density of an object by measuring only its weight and apparent weight, as long as we know the density of the fluid we are using.

CHAPTER 34.

UNIT 4 REVIEW

Key Terms and Concepts

Mass

Volume

Density

Weight

Hooke's Law

Spring Constant

Apparent Weight

Static Equilibrium

Net Force

Buoyant Force

Archimedes' Principle

Hydrostatic Weighing

Specific Gravity

Learner Outcomes

1. Compare and contrast mass, volume, density, weight and apparent weight and explain how each are measured.[2]
2. Apply the concept of static equilibrium to determine the magnitude and direction of unknown forces.[3]
3. Apply Archimedes' principle and density concepts to predict if objects will sink or float.[2]
4. Determine density from mass and volume measurements and using by hydrostatic weighing.[4]

CHAPTER 35.

UNIT 4 PRACTICE AND ASSESSMENT

Outcome 1

1) Which has greater density between a kilogram of feathers and a kilogram of pennies? Which has greater volume? Which has greater mass?

2) What is the weight in Newtons of a 3 **kg** textbook?

3) (a) Convert your own weight from pounds to Newtons.
(b) Then calculate your mass in kilograms. Show all work.

4) The acceleration due to gravity (*g*) on the moon is 1/6 that on the surface of Earth.
(a) Based on your answers to the previous question, what would your weight be on the moon?
(b) What would your mass be on the moon?

Outcome 2

5) For each object below, draw a free body diagram:

a) A car hanging from a crane (there are two forces).

b) A car skidding to a stop (there are three forces).

c) A car with the parking brake set being pushed on by a someone, but not moving (there are four forces here, but two of them are the same type).

6) A person stands on a scale.

a) What type of force is pulling them down?

b) What type of force is provided by the scale to hold them up?

c) Draw a free body diagram of this situation.

7) A 7 **N** force pushes on an object to the right and a 7 **N** force pushes on the object to the left.

(a) What is the net force?

(b) Can the object be in static equilibrium?

8) A 5 **N** force pushes on an object to the right and a 7 **N** force pushes on the object to the left.

(a) What is the net force?

(b) Can the object be in static equilibrium?

9) You push on a large box with 120 **N** of force, but it doesn't move.

(a) How large is the friction force?

(b) Draw a free body diagram of the situation.

Outcome 3

10) You are helping a 48 **lb** toddler learn to float in a swimming pool.

(a) What weight of water must the toddler displace in order to float?

(b) What volume of water must the toddler displace in order to float?

(c) Currently the toddler doesn't like water to cover his ears and holds his head mostly out of the water. You notice that it feels as though he only weighs 3 **lbs**. Draw a free body diagram of the situation.

(d) How large is the buoyant force on the toddler?

(e) If the toddler were to lower his head fully half-way into the water (past the ears), he would displace another 0.4 gallons worth of water**.** Would the toddler float then? [Hint: Water as a weight density of 8.34 **lbs/gal**]

11) An object has a volume of 0.5 $\mathbf{m^3}$ and weight of 150 **N**.

(a) What is the maximum volume of water it can displace?

(b) What weight of water can it displace?

(c) Will it float?

(d) Is the object in the previous problem more or less dense than water?

Outcome 4

12) Calculate the density of the object referred to in the previous problem.

13) An object has a weight of 5.5 **N** and an apparent weight of 3.5 **N** when fully submerged.

(a) Will the object float?

(b) Calculate the density of the object.

PART V.

UNIT 5: MAINTAINING BALANCE

Learner Objectives

1. Define center of gravity, support base, normal force, static friction and kinetic friction.[2]
2. Compare the relative torque applied to objects by various forces.[2]
3. Identify the type of equilibrium exhibited by various structures and rank their relative stability.[2]
4. Apply static equilibrium concepts to determine forces in physical situations, including normal force and friction.[3]

CHAPTER 36.

BALANCE

Warning sign indicating a rough walking surface, which isn't a problem for animals with more stable body types, such as cats and dogs. Image Credit: National Park Service

1

As an RN on MED floor, Jolene assesses each patient's fall risk according to the Morse Fall Scale, provide a nursing diagnosis (ND) for fall risk, and implement fall precautions based on the ND. The human body typically operates in many positions that are not very stable and we must constantly use our muscles to adjust our body position and counteract the tendency of our bodies to fall over. We often refer to this skill as *balance*. For the most part balance is subconscious, but watching a toddler who has just learned to walk will provide an amplified idea of how much actual work is required for humans to stay upright. Toddlers are especially unstable due to their disproportionately massive heads, and after this unit we will understand exactly why that feature so greatly affects their stability.

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1. "Rough Surface Warning"National Park Service is in the Public Domain

CHAPTER 37.

CENTER OF GRAVITY

FINDING THE CENTER OF GRAVITY

You may have heard the term center of gravity in reference to balance and you might intuitively know that a toddler’s big head raises their center of gravity, which makes them less stable than adults. We already know that the force of gravity is what gives an object weight, but what is the center of gravity? Think about which body part you feel gravity pulling on. Do you feel it pulling on just your leg, or your arm, or what? Actually, the force of gravity acts on all of your mass in the same way, according to Newton's Universal Law of Gravitation down to every single molecule and atom. If we break up your body into many many small chunks of equal mass we could calculate the tiny force of gravity on each one. If we add up all those tiny forces we get your total weight. If we average the locations of all those equal tiny forces, the resulting location would be the center of gravity. If we averaged the location of all the equal chunks of mass that would be the center of mass. Everyday objects, like humans, are small enough that gravity acts uniformly on all parts of the object and the center of gravity and the center of mass are essentially the same location. Check out the following video to learn how to experimentally find the center of gravity (mass) of an irregular object.

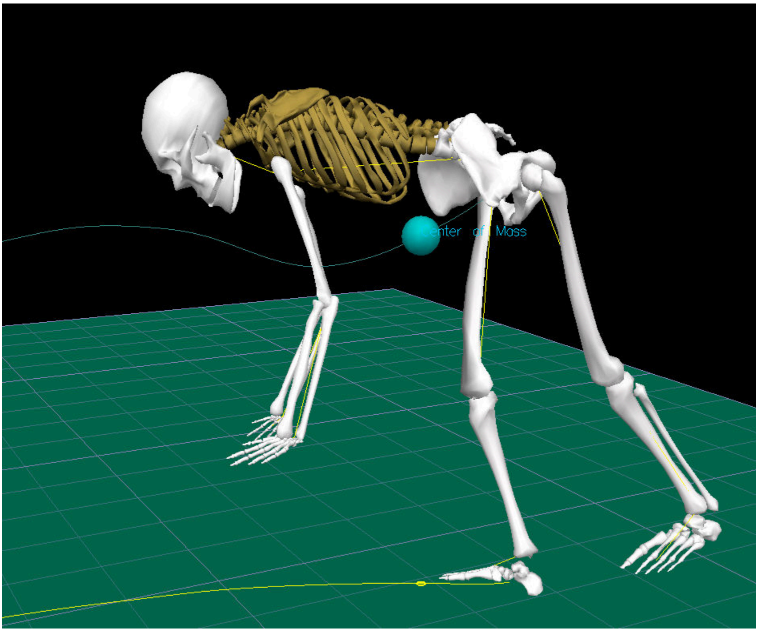
Reinforcement Exercises

BALANCE

Being out of balance means that your center of gravity is no longer above your support base (usually the space between your feet). When that happens you either fall

A YouTube element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bodyphysics/?p=1168

down or take a step to widen your support base (regain your balance). Let's examine why those are the only two options you have.



The center of gravity of an object (blue dot) is the average location of all gravitational forces. This average location does not necessarily have to be on the object. Image Credit: D. Gordon E. Robertson via wikimedia commons

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[1]

Freely rotating objects tend to rotate around their center of mass. The following video shows a neat demonstration of that phenomenon:

https://youtu.be/DY3LYQv22qY

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[1] "COM" by D. Gordon E. Robertson, Wikimedia Commons is licensed under CC BY-SA 3.0

CHAPTER 38.

SUPPORTING THE BODY

SUPPORT FORCE (NORMAL FORCE)

When standing on the ground gravity is pulling you down, but you aren't falling. In fact you are in static equilibrium so the ground must be providing a supporting force that balances your weight. The ground provides that force in response to compression caused by your weight. When solid objects push back against forces that are deforming them we call that responsive push-back the Normal Force.

Reinforcement Activity

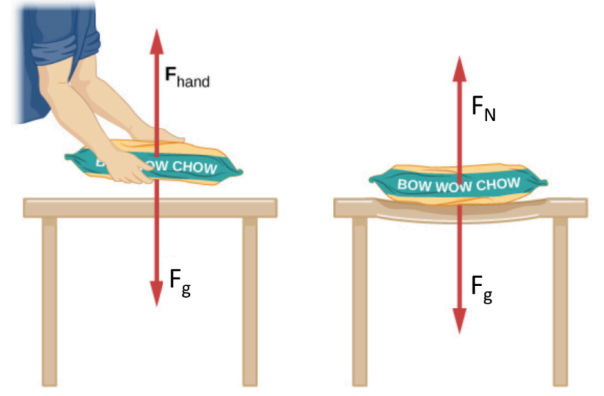
Push your finger down into your palm and feel the resistance from your palm.

That resistance is the normal force.

The normal force is a reactive force, meaning it only exists in response to a push from another object. When you pull your finger away from your palm, the normal force from your palm goes away.

Everyday Example[1]

In the diagram below, we see a person placing a bag of dog food on a table. When the bag of dog food is placed on the table, and the person lets go, how does the table exert the force necessary to balance the weight of the bag? While you wouldn't see it with your naked eye, the table sags slightly under the load (weight of the bag). This would be noticeable if the load were placed on a thin plywood table, but even a sturdy oak table deforms when a force is applied to it. That resistance to deformation causes a restoring force much like a deformed spring (or a trampoline or diving board). When the load is placed on the table, the table sags until the restoring force becomes as large as the weight of the load, putting the load in equilibrium. The table sags quickly and the sag is slight, so we do not notice it, but it is similar to the sagging of a trampoline or a hammock when you climb on.



The person holding the bag of dog food must supply an upward force equal in size and opposite in direction to the force of gravity on the food. The card table sags when the dog food is placed on it, much like a stiff trampoline. Elastic restoring forces in the table grow as it sags until they supply a normal force equal in size to the to the weight of the load. Image credit: University Physics

NORMAL FORCE AND WEIGHT

If you place an object on a table the normal force from the table supports the weight of the object. For this reason normal force is sometimes called support force. However, normal is another word for perpendicular, so we will stick with normal force because it reminds us of the important fact that the normal force always acts at an angle of 90° to the surface. That does not mean the normal force always point vertically, nor is it always equal to an object's weight. If you push horizontally on the wall, the wall pushes back (keeping your hand from moving through the wall). The force from the wall is a normal force, but it acts horizontally and is not equal to your weight.

Situations where normal force is not equal to the weight of the object. Adapted from Garscon Plancher" by Obiwancho, and "Trek on the Viedma Glacier" by Liam Quinn "U.S. Air Force Chief Master Sgt. Suzan Sangster"released by the United States Armed Forces with the ID 090815-F-3140L-048

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In each situation pictured above the normal force is not equal to body weight. In the left image the normal force is less than body weight, and acting horizontally. In the middle image the normal force is less than body weight and acting at an angle. In the right image the normal force on the drill is more than it's own weight because

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2. "Garscon Plancher" by Obiwancho , Wikimedia Commons is licensed under CC BY-SA 3.0
3. "U.S. Air Force Chief Master Sgt. Suzan Sangster", Wikimedia Commons is in the Public Domain,
4. "Trek on the Viedma Glacier" by Liam Quinn , Wikimedia Commons is licensed under CC BY-SA 2.0

Master Sgt. Sangster is also pushing down on the drill. The normal force on Master Sgt. Sangster's feet is less than her weight because she is also receiving an upward normal force from the drill handle.

Often (*N*) is used as a symbol for normal force, but we are using **N** to abbreviate for the SI force unit Newtons, so instead we will use F_N. The normal force comes up so often students often accidentally begin to refer to normal force as "natural force" instead, so watch out for that possible source of confusion.

Reinforcement Exercises: Normal Force

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