Body Physics: Supplementary Material

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Contents

What's in the Supplementary Material?

PART I

DESIGN-BUILD-TEST PROJECTS

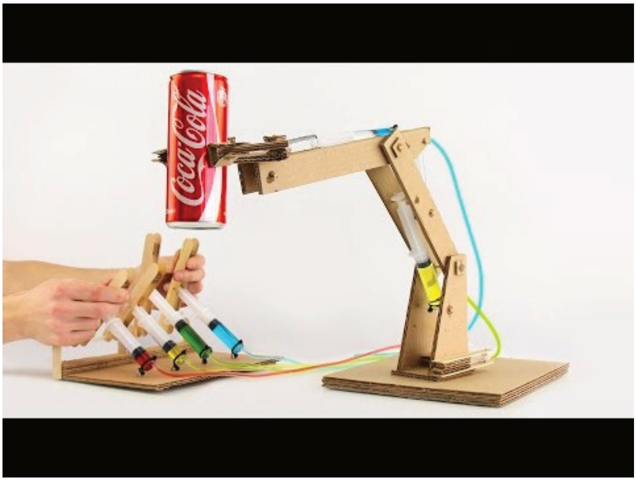
1. Biophysical Model of the Arm

Project Goals

- Use hands-on experience to reinforce physics concepts covered so far
- Jump cognition levels to *create*
- Practice critical thinking and the scientific process
- Have fun

Project Description

Build a scale articulating model of the human arm from the shoulder to the wrist. The model will include the lower arm, upper arm, elbow joint, biceps and triceps muscles and associated tendons. The model will be made out of cardboard, glue, twist ties and wooden dowels. The articulation of muscles will be done using syringes and tubing to form hydraulic actuators and twist ties will serve as tendons in similar fashion to the process seen in the following video:



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Your project assess the concepts listed below and your project grade will be determined according to the criteria listed under each concept. The project is worth 15 points overall, and the distribution of points among the criteria are listed under each concept.

1. Scientific Method: Creation process is well documented in a typed project report with the sections listed in bold below:
    - **DESIGN**
    - Neat documentation of design considerations and how they relate to concepts covered in class = 1pt
    - Neat scale diagram of your design before building begins. Must include labels and dimensions. = 1pt
    - **BUILD**

- Neat documentation of issues encountered during build = 1pt
- Neat documentation of solutions to build issues and changes to design = 1pt
- **TEST**
- Neat documentation of issues encountered during testing of design =1pt
- **REDESIGN**
- Neat documentation of solutions to testing issues and changes to design = 1pt
- Neat final updated scale diagram = 1pt

2. Unit Conversion: The model is a 2:3 scale size of a human arm.

    - Scaled 2:3 = 2pts
    - Proportionally scaled, but not 2:3 = 1pt

3. Forces and Torques: The model is capable of curling at least 1:100 the weight that a human arm can curl.

    - Curls at least 1:100 scale weight = 2 pts
    - Curls weight, but not 1:100 scale weight = 1pt

4. Levers: The model actuates with the same range of motion (in terms of elbow angle) as the human arm.

    - Articulates full human range of motion = 2 pts
    - Articulates, but not full human range of motion= 1pt

5. Stability: The model does not tip over under the 1:100 scale load.

    - Remains standing = 1pt

6. Strength of Materials: The model materials do not fracture, rupture, or otherwise fail under the 1:100 load.

    - No failure, fracture or rupture = 1pt

Additional Information to Consider:

- You may use any resource you like for guidance, however only students in you group may work on your model or add to the documentation AND ***you must cite your sources in your project report***.
- You don't have to build the control levers, you can just hold and operate your two control syringes.
- Your model does not need to rotate like the one in the example video.
- Do not build a hand, we will hang a weight from the end of your model's forearm for the testing phase.
- You do not have to generate your diagrams on the computer unless you want to. You can draw them by hand and attach them to your report as long as they are still neat, well labeled, properly scaled, and the dimensions are indicated.
- Your project will receive a group score, however students not actively participating and contributing will not receive credit for the project.
- You will be able to go through as many rounds of design/build/test as you would like within the time allotted for this project.
- All projects must have their final evaluation on or before the last day of the period allotted for the project.
- Don't hesitate to ask your instructor for help or ask clarification question regarding the project expectations.

2. Mars Lander

Project Goals

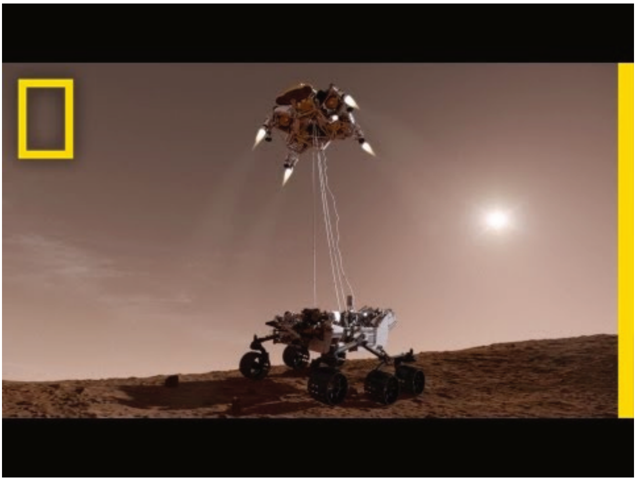
- Use hands-on experience to reinforce physics concepts covered so far
- Jump cognition levels to *create*
- Practice critical thinking and the scientific process
- Have fun

Project Description

Lander Delivery

Welcome to the first briefing for the touchdown redundancy team. Please play close attention because I am going to throw a lot of information at you.

Now, as you are aware the sky crane has emerged as the most practical method of delivering relatively massive payloads to the Martian surface. For a brief recap of that system watch the following video:



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As we know, the sky crane system successfully delivered the curiosity rover to Mars, an important step in getting this historic point, where we are now in mission design phase for the Human Exploration of Mars. Several sky crane systems will be used to deliver supplies, equipment and the return rocket ahead of the human mission.

Your Task

We calculate a low failure probability for the sky crane, but we also estimate that the large majority of that probability is concentrated during the time when the crane is within 14 **m** of the surface.

We know humans and equipment can only survive forces up to a certain threshold. Therefore, this team will design a lander which will prevent accelerations above the safety threshold for drops up to 14 **m** on Mars. This will ensure that the humans and critical equipment survive an unexpected drop to the Martian surface with no adverse effects.

The system you design to accomplish this must not rely on any other system, which would create a redundancy spiral, and that includes any electronics systems. (Therefore a parachute deployment system is not acceptable).The system must be built into the structure of the lander itself. You will be designing a Mechanical Acceleration Suppression System, or M.A.S.S.

Design and Testing Parameters:

In order to generate a diversity of design ideas the team will be split into groups. I want hands-on contributions from all members, so groups cannot be bigger than three. I also want us checking and double-checking each other's work, so no groups smaller than two.

Each group will design a system, build a model, and we will test them in our free-fall facility here in the building. The model test subjects and equipment we will use will be three raw eggs.

We must recognize that g on mars is only about 3.8 **m/s/s** compared to 9.8 **m/s/s** on Earth so you will calculate a new drop height for testing our models here on Earth.

The model lander must fall straight down from the calculated height and land within a 25 **cm** x 25 **cm** area to ensure that it lands in the safe location identified by the sky crane imaging system. (Therefore a parachute system is not acceptable).

Due to the fuel requirements and cost of launching mass into space, you are limited to a total mass of 500 **g** for your model lander system, including the payload (eggs).

Due to the size limitations of the spacecraft you are limited to a total size of 20 **cm** wide x 20 **cm** long by 30 **cm** high for your model lander system.

You are also limited on your design budget. In order to maximize the efficiency of taxpayer dollars for space exploration you are limited to the following materials, with associated costs and your total cost cannot go above 500 **USD.**

Glue: No cost
Paper: 4 **USD/gram**
Cardboard: 6 **USD/gram**
Wood (Popsicle sticks) 10 **USD/gram**
Aluminum Foil: 25 **USD/gram**

Presentation and Testing:

You will give the class an **8 minute** presentation on your model that will include the following sections:

1. Model design features
2. Physics concepts and reasoning behind your design
3. Materials cost breakdown for your model
4. Difficulties and solutions/redesigns during your project

Model Evaluation (Grading)

C-grades will be earned by:

1. correctly completing and submitting the guide calculations worksheet
2. fully participating in the design-build process
3. keeping your design within budget limitations
4. contributing to your group presentation.

B-Grades will be earned by doing the above plus:

1. landing completely within the designated area
2. preventing damage to the test subject (egg).

A-Grades will be earned by doing all of the above plus:

1. keeping within mass and size limitations

Guide Calculations:

Drop Height, Speed, and Acceleration

Using our knowledge of conservation of mechanical energy determine the Earth drop height we need to provide the same impact speed as a 14 **m** drop on Mars:

We want to limit the peak acceleration felt by the cargo to 10 **g**. The humans and equipment will be strapped tightly to the lander frame so the lander frame must not accelerate at more than 10 **g**. What is this acceleration in m/s/s?

Impact Force

Assuming your lander + payload have the maximum 300 **g** mas, calculate the maximum net force that can be applied to the lander on touchdown without exceeding the threshold acceleration:

Draw a free body diagram of the lander during impact

Determine the peak normal force that can be applied to your model by the ground in order to prevent such an acceleration. This is your safety threshold force.

You may use force plate to test version of your models and see how they react to forces of various sizes.

Impact Duration

Use the lander mass and impact speed to calculate the change in momentum of the lander upon impact.

If you design your lander to keep the average net force applied on impact to be less than 1/3 of the safety threshold, then the peak force will likely not exceed the safety threshold. Draw a F vs. t curve for the impact that illustrates this idea.

If you were to achieve this average force value of 1/3 the peak force threshold, then over what time would you need to spread the impact?

What design features will you implement to spread out the impact duration?

Testing

Record the dimensions of your lander here:
Width:_________Length:_______Height:_________
Record the mass of the lander here:_________
Record the masses and total cost of various materials used:

Record the total cost of your lander here:_______

Did your payload survive without damage?

3. Energy Efficient Home

Project Goals

- Use hands-on experience to reinforce physics concepts covered so far
- Jump cognition levels to *create*
- Practice critical thinking and the scientific process
- Have fun

Project Description

PART II

LAB EXTENSION ACTIVITIES

4. Unit 9 Lab Extension Part II: Limits on Human Performance*

Limits on Human Performance

What is the ultimate strength of the Achilles Tendon

Find or calculate the cross-sectional area of the Achilles Tendon. Cite any sources.

Based on your answer, what force can the typical Achilles Tendon supply before rupture?

In order to transfer the the force on the balls of the feet directly to the lower legs during the jump, the force on the Achilles needs to be roughly twice the force on the balls of the feet. Given the maximum force the Achilles can handle, how large of a force can be applied to the balls of the feet during the jump without rupture?

If you apply that force to the floor, what force is supplied back on your feet (Newton's 3rd Law)?

If that peak force were supplied during launch phase, what would be the peak net force? (Don't forget about gravity cancelling out some of the upward force supplied by the floor).

If the peak net force was what you found above, what would be the average net force (assuming the force curve peak-to-average force ratio as your own jump).

If that average net force were supplied over the same launch time as your jump, what would be the impulse?

What would be the change momentum during the launch?

What would be the final velocity at the end of launch phase?

How long would it take for your velocity to become zero at the peak of the jump?

What is the maximum hang time possible given the limitations of the strength of the Achilles tendon?

Determine the maximum kinetic energy a person can gain during the launch phase.

Determine the maximum height that a person can jump based on that kinetic energy (Use conservation of Energy).

Additional Limits on Human Performance

Having already found the maximum kinetic energy a person can gain during the launch phase, what is net work that would be done during the launch phase. (Work-Energy Theorem)

Using the distance the center of mass traveled during your own launch phase, calculate the work done by gravity during launch (Work equation).

Determine the work that would be done by the jumper during launch.

If the work was done over the same time interval as your launch phase, what would be the power output of the person.

Convert your answer to horsepower.

5. Unit 8 Lab Extension: Quantitative Numerical Modeling of Falling Motion with Air Resistance*

Numerical Modeling

Do the Unit 8 *Lab Extension Activity* to determine the drag coefficient of a coffee filter.

Use a spreadsheet or your favorite coding language to build the numerical model for skydiving motion described a the end of Unit 8.

Use the coffee filter drag coefficient you found, employ your program to model the acceleration, velocity and potion of a three nested coffee filters during a fall.

Measure the acceleration, velocity and position experienced by the set of coffee filters during a fall.

Graph both your measured and predicted acceleration on a single graph.

Graph both your measured and predicted velocity on a single graph.

Graph both your measured and predicted position on a single graph.

Does your model do well at prediction the coffee filter motion?

6. Unit 9 Lab Extension Part I: Replenishing Energy*

Jump Analysis Continued...

You will need to refer to the data and analysis from the Unit 9 Lab throughout this activity.

Human Performance

What is the change in kinetic energy of the person during the launch phase of the jump, from stationary to leaving the force plate?

What is the net work done on the person during the launch phase? (Work-Energy Theorem)

Use your video to find the distance the person's center of mass moved during the launch phase. Record here:

Using the distance above and the net work from the start of this section, find the average net force during the launch phase. (Work Equation)

What average force needs to be supplied by your Achilles tendon in order to have the average net force you found above. (This force needs to be large enough to cancel your weight, AND still have the net force you found above left over!)

Use this force and the launch distance you found to determine the work done by the jumper.

Where did the energy to do this work come from?

You have to supply basically the same work to stop your motion on landing than you provided to stop it on launch. How much energy must you supply for one jump?

If a person performed one of these jumps per second for a whole day, how many Joules of work would they do?

Assuming a 20% mechanical efficiency, how much energy do you actually expend to do this work? (You have to do 5x more work than actual mechanical energy you get out).

How many extra food calories is that?

You also need about 2000 Calories per day for basic metabolism, so how many 260 Calorie candy bars would you need to eat in order to maintain calorie balance?

If you did not eat any candy bars how many pounds of fat would you need to metabolize to provide this energy? Cite any sources for the calories per pound of fat metabolized.

7. Unit 10 Lab Extension: Collisions

Inelastic Collisions

- lab sheet and writing utensil
- calculator
- “frictionless” track + two carts with velcro bumpers and magnetic or rubber bumpers
- two motion sensors + computer with sensor control and analysis software (or one motion sensor and one self-tracking motion cart).

Observation

Two objects colliding and sticking together looks just like an explosion in reverse.

Question

When two objects collide and stick together, also known as a perfectly inelastic collision, are kinetic energy and momentum conserved?

Hypothesis

Based on what you know about kinetic energy and momentum during an explosion, form a hypothesis about kinetic energy and momentum conservation during a perfectly inelastic collision.

Test

Now perform this experiment on your carts and track by giving the carts an initial velocity with a light push. Use the Velcro bumpers so that the carts stick together (you may instead use the magnetic bumpers arranged so that they attract). You may start with one cart stationary or give both carts an initial velocity.

Record the measured initial (before collision) and final (after collision) velocities of each cart here, being sure to record them as positive or negative according to your own choice of directions:

Measure and record the mass of each cart:

Momentum Analysis

Calculate the initial total momentum immediately before the collision.

Calculate the final total momentum immediately after the collision

Momentum Conclusion

Do the results above support or refute your momentum hypothesis. Explain.

Kinetic Energy Analysis

Calculate the initial total kinetic energy immediately before the collision.

Calculate the final total kinetic energy immediately after the collision

Kinetic Energy Conclusion

Does the result above support or refute your kinetic energy hypothesis. Explain.

If kinetic energy was not conserved, then where did it go?

Elastic Collisions

Observation

Now attach the magnetic bumpers to your so that they repel each other and then softly collide them. What do you observe about this collision in contrast to the perfectly inelastic collision?

Question

Does this type of collision conserve kinetic energy and momentum?

Hypothesis

Form a hypothesis about kinetic energy and momentum conservation during a collision between the carts with repelling magnetic bumpers.

Test

Softly collide the carts so that they “bounce” without actually touching Record the initial and final velocities for each cart here:

Record the mass for each cart here:

Momentum Analysis

Calculate the total initial momentum of the carts:

Calculate the total final momentum of the carts:

Momentum Conclusion

Do the results above support or refute your momentum hypothesis? Explain.

Kinetic Energy Analysis

Calculate the total initial kinetic energy of the carts:

Calculate the total final kinetic energy of the carts:

Kinetic Energy Conclusion

Do the results above support or refute your hypothesis? Explain.

Was this a perfectly elastic collision? Explain.

If not, how much kinetic energy was "missing?"

Calculate a coefficient of restitution for this collision.

If this were a perfectly elastic collision then we should be able to calculate the final velocities using the elastic collision equations found at the very bottom of this web page. Use your measured initial velocities and cart masses in the elastic collision equations to calculate the expected final velocity for each cart. Show your work below.

Calculate a percent difference between the expected and observed final velocities for each cart. Was this collision elastic enough that the elastic collision equations were still accurate to within 10 **%** ?

8. Unit 10 Lab Extension: Ballistic Pendulum*

Ballistic Pendulum

The ballistic pendulum is a device used to determine the speed of objects moving too fast for conventional instruments. The basic idea is that a projectile is fired into a pendulum, which then swings upward to some height, which is measured. Working backwards, we can determine the speed of the projectile if the mass of the projectile and pendulum are known. The steps are as follows:

1. Assume friction and air resistance are negligible during the swing so we can use conservation of mechanical energy to determine the speed of the pendulum + projectile immediately after the collision.
2. Use conservation of momentum to determine the speed of the projectile immediately before the collision.

Order of Magnitude Estimate

Compress the spring on the ballistic pendulum and launch the projectile into the pendulum. Provide an order of magnitude estimate for the speed of the ball by comparing the observed speed to that of other objects that move much faster and much slower. Cite all sources.

Test

Find and record the mass of both the projectile and the pendulum:

Find the center of gravity of the pendulum when the projectile is already embedded. If it is not already marked, then estimate its location by finding where the pendulum will balance on your finger and then mark it with a piece of tape.

Measure and record the initial height of the center of gravity of the pendulum:

Fire the projectile and measure the final height of the center of gravity of the pendulum. Record below:

Analysis

Calculate the change in gravitational potential energy of the pendulum during the swing.

Use energy conservation, assuming friction and air resistance are negligible, to find the change in kinetic energy during the swing.

If the final kinetic energy is zero when the pendulum stops at its maximum height, what was the initial kinetic energy when the swing started?

Calculate the initial velocity of the pendulum when the swing started.

Use conservation of momentum to find the initial velocity of the ball before the collision. The final velocity of the collision is equal to the velocity at the start of the swing, which you found above.

Conclusion

Was your estimate for the speed of the ball correct within an order of magnitude? Explain.

9. Unit 8 Lab Extension: Modeling Terminal Velocity and Extracting Drag Coefficient*

Modeling Terminal Velocity and Drag Coefficient

Materials:

- copy of lab sheet and spreadsheet from Unit 2/3 Lab
- spreadsheet and graphing software
- for distance learners, access to online forums, videos, and help features for the spreadsheet software will likely be necessary

Lab Objectives

The objectives of this lab are:
1) derive a physical model for terminal velocity of objects falling through air,
2) test the model against terminal velocity data
3) use our model to extract useful information from the data

Build a Physical Model

Terminal velocity is the maximum speed reached by a falling object. Therefore, once a falling object has reached terminal velocity then it is no longer accelerating and we can say the velocity is constant, but not zero. This state is known as ___________ equilibrium.

When an object is in the state you described above, what can you say about the total force on the object?

Draw a free body diagram (FBD) of the falling object indicating the forces acting on it. Be sure to label the forces. [Hint: there are two forces].

Your diagram should show that the two forces are the same size, but pointing in opposite directions so that they cancel out. If this were not the case, then the object would not be in ____________ equilibrium. Represent this concept with an equation that sets the two forces equal:

One of the forces should be gravity (weight). Rewrite your equation, but replace the force of gravity in your equation with the formula for calculating the force of gravity on an object near the surface of the Earth:

The other force should be the drag force. Rewrite your equation, but replace that force in your equation with the formula for drag force:

Now you should have an equation that relates drag coefficient, air density, cross-sectional area and velocity to object mass and ***g***. This equation is only true when the object is in equilibrium, so the velocity in your equation must be terminal velocity. Add a subscript T to your velocity to indicate this (v_T). Solve your equation for terminal velocity, showing your work in the space below. You may ask for help with the algebra.

Now we have a physical model for the terminal velocity. The model predicts that terminal velocity is proportional to the ___________________ of the mass. Stated another way, the terminal velocity depends on mass to the _______ power.

Hypothesis

We can turn the previous statements into a quantitative hypothesis: *If identically shaped objects of different mass are dropped under the same conditions, then the terminal velocity the objects will be proportional to the _____________ of the mass.*

Acquire Test Data

We already have the terminal velocity data for coffee filters that we acquired during the Unit 2/3 Lab, so let's use that. Open up the spreadsheet you created during the Unit 2/3 Lab.

Analyze

Fit a trend line to the data. We don't yet know what type of curve should fit, so use a power fit. This will tell us how terminal velocity depends on mass according to the data.

Write your fit equation here:________________

Record the R^2 value here:_____________ The R^2 value gives you an idea of how well the equation fits your data. The closer R^2 is to one the better the fit.

Would you say that your equation fits the data well? Explain.

What power is the mass (x-variable) raised to in your equation? Is it 0.5,1, 2, 3, or something else?

Conclusion

A power of 1 would suggest terminal velocity is proportional to mass. A power of 2 would suggest terminal velocity is proportional to mass squared. A power of 1/2 would say that the terminal velocity is proportional to the square root of the mass. Does your data support your quantitative hypothesis? Explain.

Physical and Empirical Models

Your fit equation represents a quantitative ***empirical*** model. We could use the model to try to predict the terminal velocity of some other filter masses, but the model is only based on data, it doesn't rely on any physics concepts to explain what we are observing.

Your equation for terminal velocity is a quantitative ***physical*** model because it allows us to predict values for terminal velocity

AND it provides information about the underlying physics behind the behavior we observe.

If we were to test your two types of models many more times for many types of objects and they always did well at predicting the experimental results then we would say the models have been ***validated***.

Could either of these models become part of a ***theory***? Explain.

Could either of these models become part of a ***Law***? Explain.

Extracting Model Parameters*

We have a physical model for terminal velocity, and we can quickly look up or measure all of the parameters except the drag coefficient. Combing our data and our physical model will allow us to extract that parameter value for drag coefficient.

Write down your physical model and immediately below it write down the equation you fit to the data. Compare the two equations to determine what combination of physical parameters must equal the number in front of ***x*** that you see in your fit equation. (Remembering that the ***x*** in your equation represents mass and the ***y*** represents terminal velocity).

Write and equation between the parameters and the number and solve it for drag coefficient. Show your work.

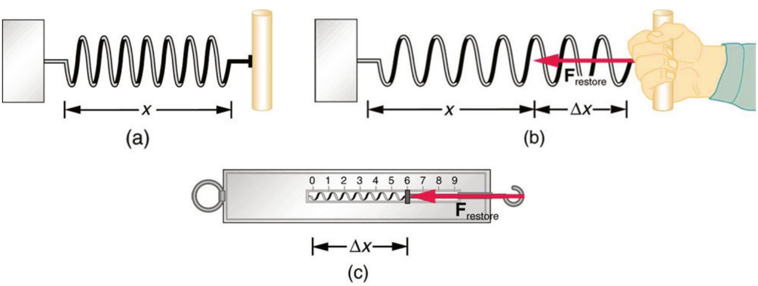
Now put in the known values for the other parameters and calculate the drag coefficient, including units. Show your work below.

You have now tested your physical model against the data and used the data to extract an unknown parameter of the physical model. That is real heavy-duty science right there!

10. Measuring Weight

Springs

We have learned that materials stretched within their linear region exhibit linear stress–strain behavior. Springs allow us to adjust the amount of strain that occurs for a given stress and increase the size of the linear region. For example, take a steel rod one foot in length and the diameter of a clothing thread and you would not be able to noticeably stretch that rod with your bare hands. 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,

1. OpenStax University Physics, University Physics Volume 1. OpenStax

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.

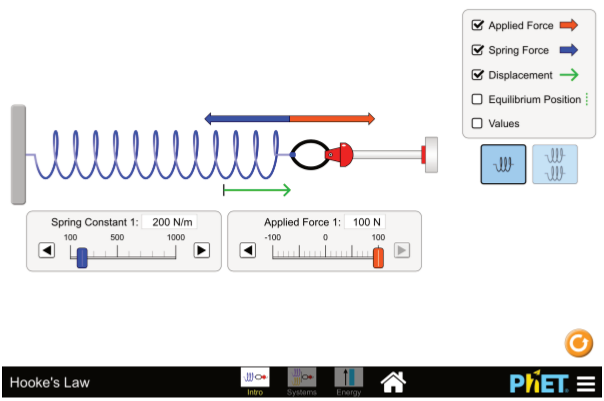
\begin{equation}

F_R = k \Delta x

\end{equation}

A higher spring stiffness means the spring shows a greater resistance to stretching or compressing. Spring stiffness is often called the spring constant.

Check out this simulation of Hooke's Law:



Reinforcement Activity

If the spring scale shown in the previous image reads 6 **N**

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

when Δx is 3 **cm**, what is the spring constant (stiffness) in units of **N/cm**?

The standard unit for spring constant is **N/m**. Convert your answer from **N/cm** to **N/m**.

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. In order to use a spring scale to measure weight we can multiply the measured stretch distance by the known spring constant to find the restoring force applied by the spring. 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 every time we use the scale. If the object being weighed is in equilibrium then the restoring force and the weight of the object are the same, and so by measuring the restoring force with the scale we then know the weight. 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 in the image below. If instead the scale is tilted so gravity and restoring force don't have opposite directions, the reading may be inaccurate. If the object and/or scale are not in equilibrium while holding it, then the reading may be inaccurate, and we will learn more about how and why in later units. Either way, the scale is only accurate if the object being weighed remains in equilibrium during the measurement.

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

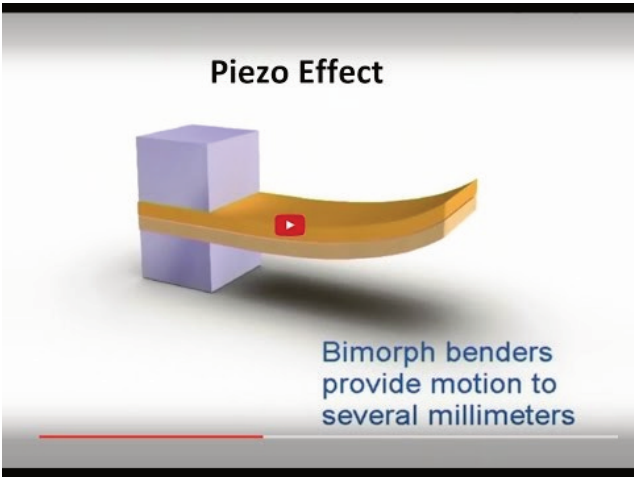
Many analog scales are based on multiple springs or the resistance to deformation by objects other than springs, but they still determine weight using measurement of a deformation combined with a known relation between deformation and force.

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

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 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.

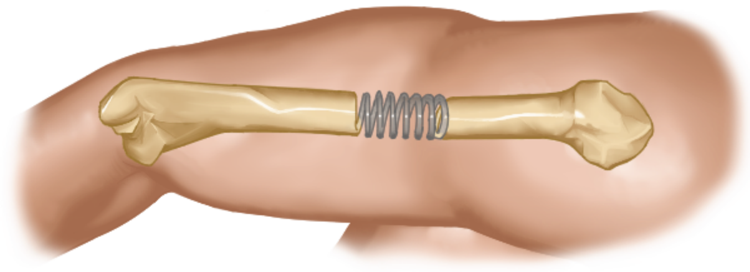


A YouTube element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bpsupmat/?p=203

11. Modeling Body Tissues as Springs*

Spring Constants of Body Parts

When tissues are put under stress within their elastic region they exert a restoring force that is proportional to the displacement. They also return back to their original size and shape when the force causing the deformation is removed. This exactly how springs behave, so we can model tissues, and any other material within its elastic region, as a collection of springs.



Artist's conception of the elastic behavior body tissues. "Armcoil" by Sasha Lynch.

Consider modeling the humerus bone as a spring, as depicted in the image above. We can think of compressing a bone that has twice the cross-sectional area of the humerus as equivalent to compressing two of the original springs at the same time, which would require twice the applied force to create the compression distance (displacement). Therefore that bone would have twice the spring constant of the humerus. We can also think of a bone that is twice as long as the humerus as equivalent to compressing two of the original springs placed end-to-end. Each spring will only have to compress half of the total distance, so that would require only half the force to create the same total compression distance. Now we can see that the size of an object affects the spring constant. As a result, the force required to achieve a particular compression or stretch is different for different sized objects, even when they are made of the same material. In order to study the elastic properties of a material such as bone, independent of how big the bone is, then we need to remove the effect of size. That is why we have been working with stress, strain, and elastic modulus rather than force, displacement, and spring constant.

Relating Spring Constant and Elastic Modulus

We have learned that the spring constant tells us how much force is required to stretch a spring a certain distance. We have also learned that the elastic modulus tells us how much stress is required to cause a certain strain. It seems like these concepts are very similar, but not quite identical, which is true. The stress and strain relation within the linear region is really just Hooke's Law after accounting for the amount and shape of the material being deformed, which allows us to analyze the material itself independent of the size of the object. Let's see how elastic modulus and spring constant are related.

If we start with the elastic stress-strain relation:

\begin{equation}
stress = E \cdot strain
\end{equation}

And then replace stress and strain with their definitions from previous chapters:

\begin{equation}
\frac{Force}{Area} = E \frac{\Delta L}{L_0}
\end{equation}
We can rearrange to get force and stretch distance on opposite sides
\begin{equation}
Force = E \frac{Area}{L_0} \Delta L
\end{equation}
Which looks exactly like Hooke's Law if the spring constant of an object is just all the stuff sitting in front of the stretch distance:
\begin{equation}
k = E \frac{Area}{L_0}
\end{equation}
Now we can see that the elastic property of materials causes them to behave like springs. The human body has adapted to take advantage of the springy nature of tissues to walk more efficiently, jump higher, and generally improve performance in many activities. Upcoming units will help us to understand the physics behind these adaptations.

Everyday Example

Earlier we stated that a typical Achilles tendon would stretch by about the width of a human hair when an additional 480 **lbs** (2135 **N**) of tension was applied after un-crimping. How did we arrive at that surprising figure?

First we looked up the elastic modulus of the Achilles tendon and found the value to be 1.2 **GPa**.[1]

1. "In vivo human tendon mechanical properties" by Constantinos N

Then we looked up the typical length and diameter of the Achilles tendon and found 0.15 **m** for the length and 0.018 **m** for the minimum diameter.[2]

We approximated the cross-sectional area by assuming the tendon cylindrical with circular cross-section:

\begin{equation*}

A_x = \pi r^2 = \pi \left(\frac{0.018 \,\bold{m}}{2} \right)^2 = 1.0\times 10^{-3} \,\bold{m^2}

\end{equation*}

Then we inserted the elastic modulus, original length, and area into the equation for spring constant:

\begin{equation}

k = E \left(\frac{Area}{L_0}\right) = 1.2 \times 10^9 \,\bold{\frac{N}{m^2}}\left(\frac{1.0\times 10^{-3} \,\bold{m^2}}{0.15 \,\bold{m}}\right) = 8.1 \times 10^6 \,\bold{\frac{N}{m}}

\end{equation}

Now that we have the spring constant for a typical tendon, we used Hooke's Law to relate the tendon force and the stretch distance.

\begin{equation*}

F = k\Delta x

Maganaris and John P Paul, U.S. National Library of Medicine, National Institutes of Health

2. "Achilles tendon: functional anatomy and novel emerging models of imaging classification" by Angelo Del Buono, Otto Chan, and Nicola Maffulli, U.S. National Library of Medicine, National Institutes of Health

\end{equation*}

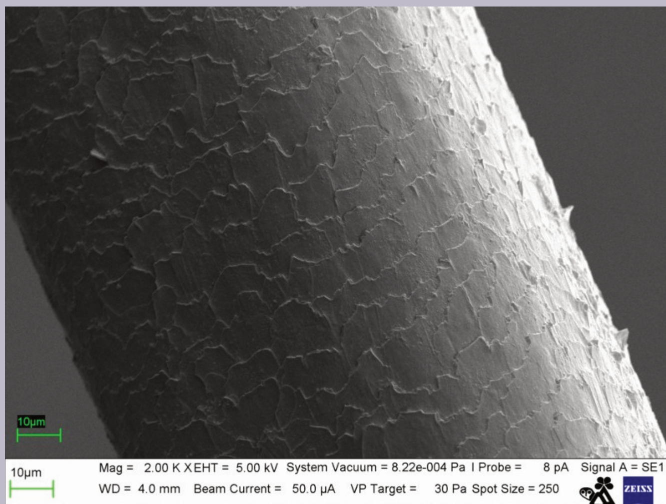
Dividing both sides by k isolates the stretch distance, which is what we want. Then we insert the k and F values, remembering to use Newtons for our force unit to match the units on the spring constant we calculated.

\begin{equation*}

\Delta x = \frac{F}{k} = \frac{2135 \,\bold{N}}{8.1 \times 10^6 \,\bold{\frac{N}{m}}} = 2.6\times 10^{-4} \,\bold{m}

\end{equation*}

We can write our answer above in scientific notation as $260 \times 10^{-6} \bold{m}$ or using a metric prefix $260\bold{\mu m}$. Typical human hair is also a few hundred $\bold{\mu m}$ as you can see from this 2000x magnification image of a human hair produced by a scanning electron microscope (SEM).



Human hair imaged with a scanning electron microscope at 2000x magnification. Notice the green scale bar on lower left showing 10 **μm***, indicating that the hair is roughly 100* **μm** *in diamter. Image credit: "Human Hair 2000X" by MUSE via Wikimedia Commons*

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3. "Human Hair 2000X" by MUSE via Wikimedia Commons [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)]

12. Unit 7 Review

Key Terms and Concepts

Tension

Compression

Stress

Strain

Ultimate Strength

Elastic Region

Elastic Limit

Plastic Region

Yield Point

Brittle

Ductile

Elastic Modulus

Hooke's Law

Spring Constant

Learner Objectives

1. Identify and define the features of a stress-strain curve, including stress, strain, elastic region, elastic modulus, elastic limit, plastic region, ultimate strength, and fracture/rupture.[2]
2. Acquire stress-strain data and calculate the elastic modulus from stress-strain data.[4]
3. State Hooke's Law and define spring constant.[3]
4. Apply the Hooke's Law along with the definitions of stress, strain, and elastic modulus to calculate the deformations of structures. [3]

13. Unit 7 Practice and Assessment

Outcome 1

1) A person with a weight of 715 **N** hangs from a climbing rope 9.2 **mm** in diameter.

a) What is the cross-sectional area of the rope in $\mathbf{m^2}$?

b) What is the stress applied to the rope?

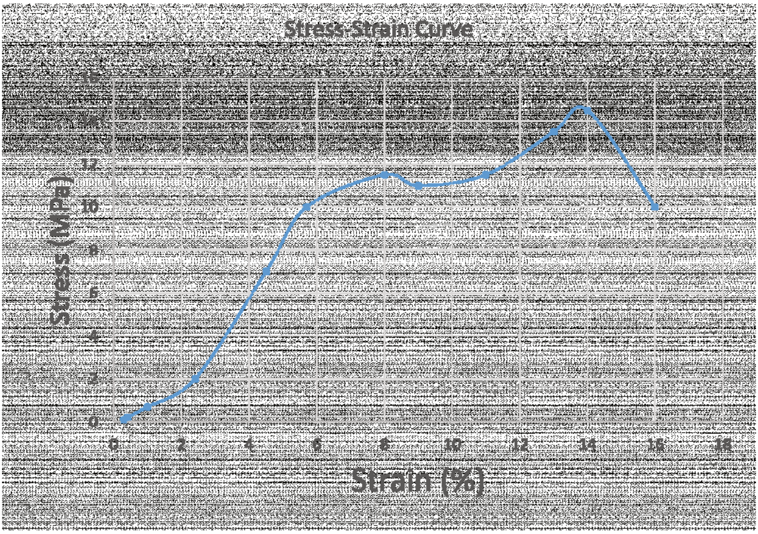
2) A particular 60 **m** climbing rope stretches by 0.15 **m** when a 715 **N** person hangs from it.

a) What is the strain in the rope?

b) What is the strain in the rope as a percentage?

3) Label the following features in the stress-strain curve of a hypothetical material seen below:

- Toe region
- Elastic region
- Yield point
- Plastic Region
- Ultimate Strength
- Rupture Point
- Failure Region



Data adapted with permission from rubber band stress-strain data originally acquired by Umpqua Community College Students: Brittany Watts, Ashlie DeHart, Hanna Wicks and Juan Martinez.

Outcome 2

4) Use the data in the previous graph to determine the elastic modulus of the hypothetical material. Be sure to convert the strain from % stretch back to fractional stretch before doing your calculations.

Outcome 3

5) Answer the following questions regarding the material used to create the created the stress-strain graph above.

a) How much force could be applied to a 2 **m** x 2 **m** x 10 **m** long block of this material before reaching the ultimate strength?

b) When operating in the elastic region, how much additional stress would be required to cause an additional strain of 0.01?

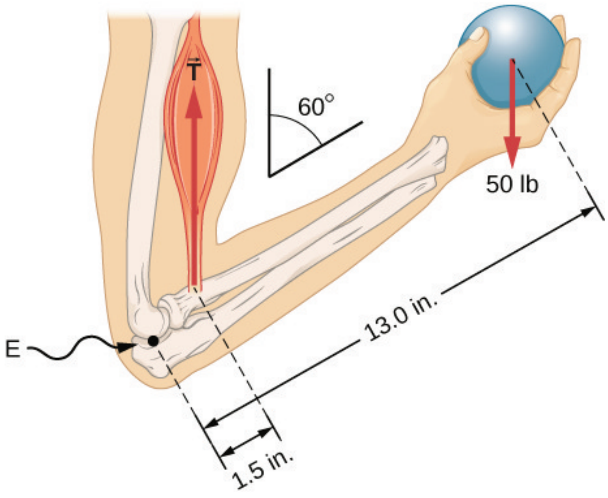
c) What force would cause that amount of stress you found in part b on the 2 **m** x 2 **m** block?

d) What actual length would the 10 **m** long material stretch when put under the strain of 0.01?

e) What is the effective spring constant of this 2 **m** x 2 **m** x 10 **m** long block of this material?

14. Forces on the Forearm while Curling

In this unit we use the example of holding a 50 **lb** weight in the hand to learn more about various forces acting within the body, how they are generated, and how to determine their magnitude and direction.



The elbow joint flexed to form a 60° angle between the upper arm and forearm while the hand holds a 50 **lb** *ball . Image Credit: Openstax University Physics*

[1]

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

The tension force in the biceps is trying to lift and rotate the forearm around the elbow joint. The force of gravity is pulling down on the ball and the forearm, causing rotation in the opposite direction to that caused by the biceps. Our intuition tells us that the muscle tension needs to somehow counteract the weight of the ball with the forearm acting as a sort of lever. That's where we'll start to solve this example.

We know the ball weighs 50 **lbs**. If we wanted to include the effect of the weight of the forearm in our example problem we could look up a typical forearm weight and also look up where the center of gravity of the forearm is located. Instead let's take this opportunity to practice making *justified* assumptions. We know that forearms typically weigh only a few pounds, but the ball weight is 50 **lbs**, so the forearm weight is about an order of magnitude (10x) smaller than the ball weight[2]. Therefore, let's assume the forearm weight doesn't matter much and continue solving our biceps force problem only including the weight of the ball, which acts at the center of gravity of the ball.

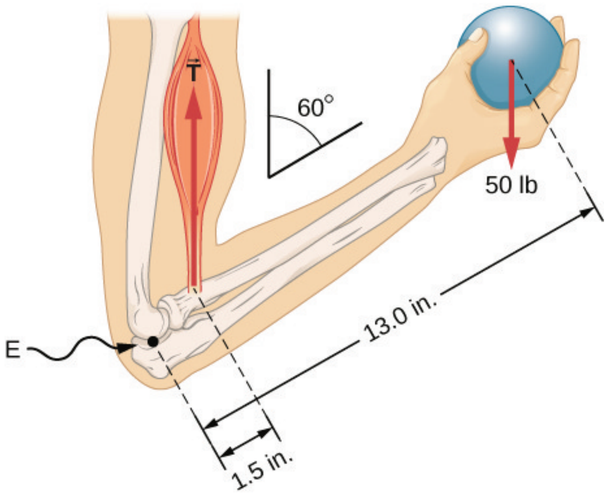
2. "Weight, Volume, and Center of Mass of Segments of the Human Body" by Charles E. Clauster, et al, National Technical Information Service, U.S. Department of Commerce

15. Body Levers

Lever Classes

A lever is a rigid object used to make it easier to move a large load a short distance or a small load a large distance. There are three classes of levers, and all three classes are present in the body[1][2]. For example, the forearm is a 3rd class lever because the biceps pulls on the forearm between the joint (fulcrum) and the ball (load). To see these body levers in action check out this short video animation identifying levers in the body.

1. "Lever of a Human Body" by Alexandra, The Physics Corner
2. "Kinetic Anatomy With Web Resource-3rd Edition " by Robert Behnke , Human Kinetics

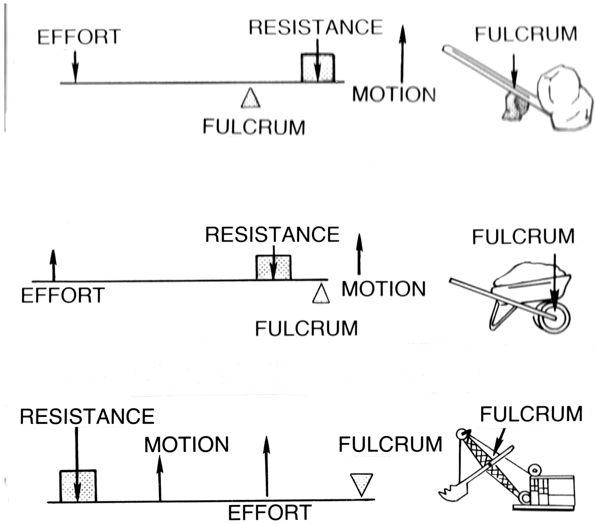


The elbow joint flexed to form a 60° angle between the upper arm and forearm while the hand holds a 50 ***lb*** *ball . Image Credit: Openstax University Physics*

3

Using the standard terminology of levers, the forearm is the lever, the biceps tension is the effort, the elbow joint is the fulcrum, and the ball weight is the resistance. When the resistance is caused by the weight of an object we call it the load. The lever classes are identified by the relative location of the resistance, fulcrum and effort. First class levers have the fulcrum in the middle, between the load and resistance. Second class levers have resistance in the middle. Third class levers have the effort in the middle.

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



First (top), second(middle), and third(bottom) class levers and real-world examples of each. Image Credit: Pearson Scott Foresman

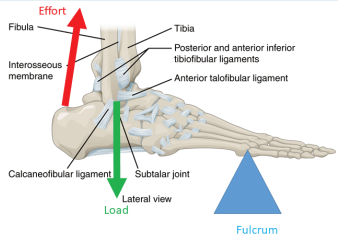
4

For all levers the effort and resistance (load) are actually just forces that are creating torques because they are trying to rotate the lever. In order to move or hold a load the torque created by the effort must be large enough to balance the torque caused by the load. Remembering that torque increases as the force is applied farther from the pivot, the effort needed to balance the resistance must depend on the distances of the effort and resistance from the pivot. These distances are known as the effort arm and resistance arm (load arm).

4. "Lever" by Pearson Scott Foresman , Wikimedia Commons is in the Public Domain

Reinforcement Activity

Identify the class of lever created by the foot and the calf muscle when raising the heel off the ground.



The foot acting as a lever arm with calf muscle supplying an upward effort, the weight of the body acting as downward load, and the ball of the foot acting as the fulcrum. Image adapted from OpenStax Anatomy and Physiology

5

5. OpenStax, Anatomy & Physiology. OpenStax CNX. Jun 25, 2018 http://cnx.org/contents/14fb4ad7-39a1-4eee-ab6e-3ef2482e3e22@10.1.

Mechanical Advantage

The ratio of load to effort is known as the mechanical advantage (MA). For example if you used a second class lever (like a wheelbarrow) to move 200 **lbs** of dirt by lifting with only 50 **lbs** of effort the mechanical advantage would be four.

Increasing effort arm reduces the size of the effort needed to balance the load, which means greater mechanical advantage. In fact for a lever, the mechanical advantage is equal to the ratio of the effort arm to resistance arm.

\begin{equation*}
MA = \frac{load}{effort} = \frac{effort\, arm}{load\, arm}
\end{equation*}

Bicep Tension

We are now ready to determine the bicep tension in our forearm problem. The effort arm was 1.5 **in** and the load arm was 13.0 **in**, so the load arm is 8.667 times longer than the effort arm.

\begin{equation*}
\frac{13\,\bold{\cancel{in}}}{1.5\,\bold{\cancel{in}}} = 8.667
\end{equation*}

That means that the effort needs to be 8.667 times larger than the load, so for the 50 **lb** load the bicep tension would need to be 433 **lbs**! That may seem large, but we will find out that such forces are common in the tissues of the body!

*Adjusting Significant Figures

Finally, we should make sure our answer has the correct significant figures. The weight of the ball in the example is not written in scientific notation, so it's not really clear if the zeros are placeholders or if they are significant. Let's assume the values were not measured, but were chosen hypothetically, in which case they are exact numbers like in a definition and don't affect the significant figures. The forearm length measurement includes zeros behind the decimal that would be unnecessary for a definition, so they suggest a level of precision in a measurement. We used those values in multiplication and division so we should round the answer to only two significant figures, because 1.5 **in** only has two (13.0 **in** has three). In that case we round our bicep tension to 430 **lbs**, which we can also write in scientific notation: $4.3 \times 10^2 \,\bold{lbs}$.

Reinforcement Activity

Calculate the mechanical advantage of the lever system in our forearm example. [Hint: your answer should be less than one.]

Range of Motion

We normally think of levers as helping us to use less effort to hold or move large loads, so our results for the forearm example might seem odd because we had to use a larger effort than the load. The bicep attaches close to the elbow so the effort arm is much shorter than the load arm and the mechanical advantage is less than one. That means the force provided by the bicep has to be much larger than the weight of the ball. That seems like a mechanical disadvantage, so how is that helpful? If we look at how far the weight moved compared to how far the bicep contracted when lifting the weight from a horizontal position we see that the purpose of the forearm lever is to increase range of motion rather than decrease effort required.

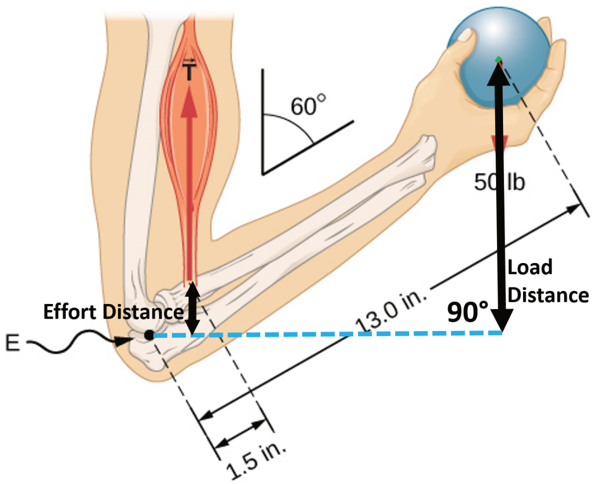


Diagram showing the difference in distance covered by the contracting bicep and the weight in the hand when moving the forearm from horizontal.Image Adapted from Openstax University Physics

Looking at the similar triangles in a stick diagram of the forearm we can see that the ratio of the distances moved by the effort and load must be the same as the ratio of effort arm to resistance arm. That means increasing the effort arm in order to decrease the size of the effort required will also decrease the range of motion *by the same factor*. Therefore the load was moved 8.667x farther than the distance contracted by the biceps muscle in our forearm example.

It's interesting to note that while moving the attachment point of the bicep 20% closer to the hand would make you 20% stronger, you would then be able to move your hand over a 20% smaller range.

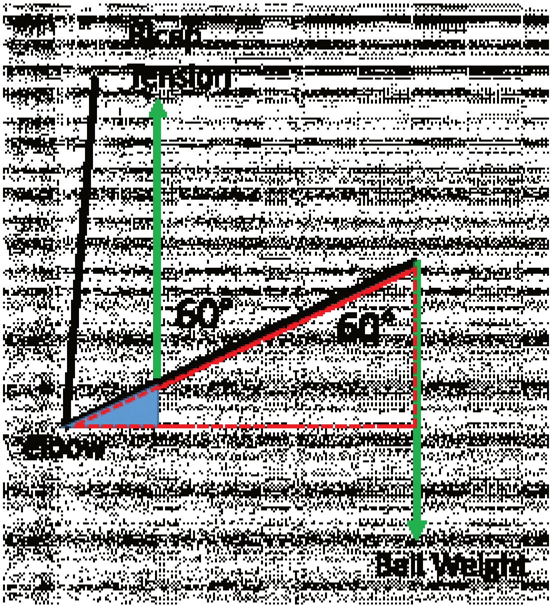


Diagram of the forearm as a lever, showing the similar triangles formed by parts of the forearm as it moves from 90 degrees to 60 degrees from horizontal. The hypotenuse (long side) of the smaller blue triangle is the effort arm and the hypotenuse of the larger dashed red triangle is the load arm. The vertical sides of the triangles are the distances moved by the effort (blue) and the load (dashed red).

For third class levers the load is always farther from the fulcrum than the effort, so they will always increase range of motion, but that means they will always increase the amount of effort required by the same factor. Even when the effort is larger than the load as for third class levers, we can still calculate a mechanical advantage, but it will come out to be less than one.

Second class levers always have the load farther from the pivot than the effort, so they will always allow a smaller effort to move a larger load, giving a mechanical advantage greater than one.

First class levers can either provide mechanical advantage or increase range of motion, depending on if the effort arm or load arm is longer, so they can have mechanical advantages of greater, or less, than one.

A lever cannot provide mechanical advantage and increase range of motion at the same time, so each type of lever has advantages and disadvantages:

Comparison of Advantages and Disadvantages of Lever Classes

Lever Class	Advantage	Disadvantage
3rd	**Range of Motion**The load moves farther than the effort. (*Short bicep contraction moves the hand far*)	**Effort Required**Requires larger effort to hold smaller load. (*Bicep tension greater than weight in hand*)
2nd	**Effort Required**Smaller effort will move larger load. (*One calf muscle can lift entire body weight*)	**Range of Motion**The load moves a shorter distance than the effort. (*Calf muscle contracts farther than the distance that the heel comes off the floor*)
1st (effort closer to pivot)	**Range of Motion**The load moves farther than the effort. (*Head moves farther up/ down than neck muscles contract*)	**Effort Required**Requires larger effort to hold smaller load.
1st (load closer to pivot)	**Effort Required**Smaller effort will move larger load.	**Range of Motion**The load moves shorter distance than the effort.

Reinforcement Activity

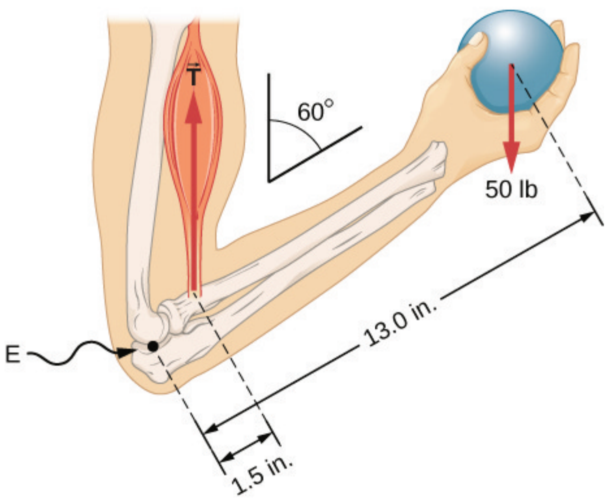
If you used a wheelbarrow to move 200 **lbs** of dirt by lifting with 50 **lbs** of effort, what is the mechanical advantage?

If the handles of the wheelbarrow are 2.0 **m** from the wheel axle (fulcrum) then how far from the fulcrum is the center of gravity of the the dirt?

To lift the dirt load 3 **in**, what distance do you have to lift the handles?

16. Forces in the Elbow Joint

In the previous chapter we found the biceps tension force in our example problem to be 430 **lbs**! You may have noticed that when we found the biceps tension we completely ignored the forces acting on the elbow joint. We were allowed to do this because *forces acting on the fulcrum of a lever don't cause the lever to rotate.* Just because the forces on the elbow don't cause rotation, that doesn't mean they aren't important. Those forces can certainly damage the joint if they get too large. Let's try to find out how big those forces are for our example problem.



The elbow joint flexed to form a 60° angle between the upper arm and forearm while the hand holds a 50 ***lb*** *ball . Image Credit: Openstax University Physics*

[1]

In our example of holding a weight in the hand the forearm is not moving and it's in equilibrium so it can't start moving. The forearm is in static equilibrium. Structures in static equilibrium have no net force, no net torque, and they aren't moving. These structures won't move unless a new force pushes them out of equilibrium.

The forearm is holding still and not moving so it must be in static equilibrium and all the vertical forces must be canceling out. If the vertical forces didn't cancel out the forearm would begin to move up or down. We already know that the weight of the ball is 50 **lbs** downward and the bicep tension is 433 **lbs** upward. The weight cancels 50 **lbs** worth of the muscle tension, leaving behind a remaining 483 **lbs** of upward force. The forearm is in static equilibrium, so the vertical force on the end of the forearm at the elbow must cancel out this 483 **lbs** upward force, meaning that the vertical force on the elbow end of the forearm is 483 **lbs** downward. This force comes from the upper arm bone (humerus) pushing down on the end of the forearm bones (radius and ulna). Adjusting our significant figures, we should report this force as 480 **lbs**.

Reinforcement Exercises

Draw a free body diagram of the elbow showing the forces from the ball weight, the bicep tension, and the upper arm pushing on the forearm. The values for all of these forces are given in the previous paragraph.

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

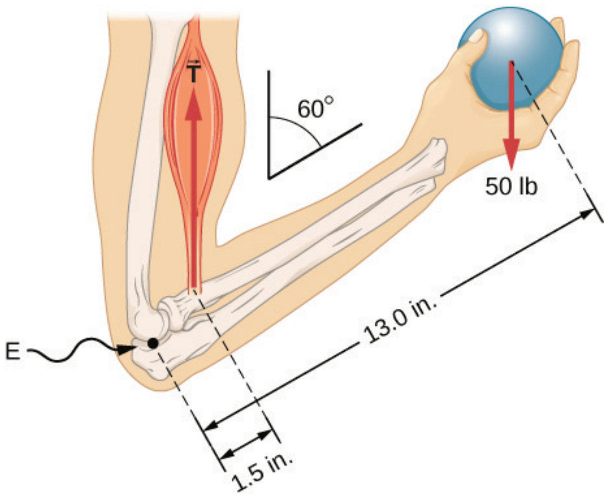
Horizontal Elbow Forces

The horizontal forces must all cancel out because the forearm is in static equilibrium, but there are no horizontal forces in our example to begin with, so that's it. We're finished analyzing the forces on the forearm while holding a 50 **lb** ball!

17. Friction in Joints

Normal Force and Friction in the Elbow

In the previous chapter we found that the upper arm bone (humerus) exerts 480 **lbs** of force on the pinkie-side forearm bone (ulna) for the scenario shown below:



The elbow joint flexed to form a 60° angle between the upper arm and forearm while the hand holds a 50 ***lb*** *ball . Image Credit: Openstax University Physics*

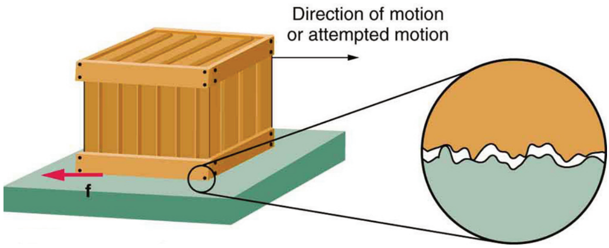
1

1. OpenStax University Physics, University Physics Volume 1. OpenStax

There are two types of forces that could be acting between the upper and lower arm bones to add up to this total 480 **lbs** of vertical force. The first is normal force, which we have already learned is the push-back provided by any object in response to being deformed.

Along with normal force, the other force that could occur between two bones is friction (F_f). Friction is the force that resists objects sliding against one another. Rub your palms together, the resistance you feel is friction. Complimentary to normal force, which only points perpendicular to surfaces, friction only points parallel to surfaces. Friction can only exist when two objects are attempting to slide past one another, so it is also reactive like normal force. If you don't try to rub your palms, you don't feel any resistance. Of course two surfaces have to touch to have friction, so you can't get friction without normal force. In fact, frictional force is proportional to normal force.

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



Frictional forces always oppose motion or attempted motion between objects in contact. Friction arises in part because of the roughness of the surfaces in contact, as seen in the expanded view. In order for the object to move, it must rise to where the peaks can skip along the bottom surface. Thus a force is required just to set the object in motion. Some of the peaks will be broken off, also requiring a force to maintain motion. Much of the friction is actually due to attractive forces between molecules making up the two objects, so *that even perfectly smooth surfaces are not friction-free. Such adhesive forces also depend on the substances the surfaces are made of, explaining, for example, why rubber-soled shoes slip less than those with leather soles.*

Reinforcement Activity

Rub your palms together. Now push your palms together hard and try to slide them at the same time.

Now the normal force is larger causing the frictional force to grow in proportion.

There are two categories of friction. Static friction($F_{f,s}$) acts between two surfaces when they are attempting to slide past one another, but have not yet started sliding. Static friction is a reactionary force because it only exists when some other force is pushing an object to attempt to cause it to slide across a surface. Static friction adjusts to maintain equilibrium with whatever other force is doing the pushing or pulling, but static friction has a maximum value. If the applied force gets larger than the maximum static frictional value, then static friction can't maintain equilibrium and the object will slide. Kinetic friction ($F_{f,k}$) acts whenever two surfaces are sliding past one another, whether or not some other force is pushing the object to keep it sliding. If there is not another force pushing the object to keep is sliding, then kinetic friction will eventually stop the sliding object, but we will learn more about that later. Static friction is larger than kinetic friction. Choose the friction simulation from the simulation set to see how static and kinetic friction behave.

An interactive or media element has been excluded from this version of the text. You can view it online here:
https://openoregon.pressbooks.pub/bpsupmat/?p=172

Reinforcement Activity

Place a heavy box or book or other object on a desk, table, or the floor. Push the object with your hand, but not hard enough to make it slide. At this point static friction is reacting to your push and exerting a force to perfectly balance your push. The balance between static friction and your push keeps the object in static equilibrium and it doesn't move.

Now push the object hard enough that it starts to slide. Notice that starts with a jerk. The jerky motion occurs because static friction is larger than kinetic friction. After you "break" static friction and the object starts to move and kinetic friction kicks. Kinetic friction is smaller than static friction so the object jerks forward before you have time to react and decrease your push force to match up with the smaller kinetic friction.

We now know that friction force is proportional to normal force and that there are two types of friction, static and kinetic. The final concept that affects friction is the roughness, or alternatively the smoothness, of the two surfaces. The coefficient of friction (μ) is a unitless number that rates the roughness and is typically determined experimentally. The static frictional force is larger than the kinetic frictional forces because μ_s is larger than μ_k. Take a look at the table of static and kinetic friction coefficients found below. You can find more values in this massive table of static friction coefficients.

Table of static and kinetic friction coefficients for various surface pairs[2]

System	Static friction, μ_s	Kinetic friction, μ_k
Rubber on dry concrete	1.0	0.7
Rubber on wet concrete	0.7	0.5
Wood on wood	0.5	0.3
Waxed wood on wet snow	0.14	0.1
Metal on wood	0.5	0.3
Steel on steel (dry)	0.6	0.3
Steel on steel (oiled)	0.05	0.03
Teflon on steel	0.04	0.04
Bone lubricated by synovial fluid	0.016	0.015
Shoes on wood	0.9	0.7
Shoes on ice	0.1	0.05
Ice on ice	0.1	0.03
Steel on ice	0.4	0.02

Notice that two surfaces are always listed in the table; you must have two surfaces to define a μ. When someone asks a question like, "what is the μ of ice?" they usually mean between ice and ice, but its best to avoid asking such questions and just always reference two surfaces.

We can sum up everything we have learned about friction in two

2. **OpenStax University Physics, University Physics Volume 1. OpenStax CNX. Aug 2, 2018 http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@11.1.**

equations that relate the friction forces to the friction coefficient for two surfaces and the normal force acting on the surfaces:

Max static friction before release:

$$F^{max}_{f,s} = \mu_{s}F_{N}$$

Kinetic friction once moving:

$$F_{f,k} = \mu_{k}F_{N}$$

Everyday Exmaple

Firefighter candidates must complete a physical ability test (PAT) that includes dragging a dummy across the floor. The PAT for the city of Lincoln Nebraska specifies that candidates must drag a human form dummy weighing 170 **lbs** for 25 feet, around a barrel, and then back across the starting point for a total distance of 50 feet in six minutes or less. The candidates may only drag the dummy using the pull harness attached to the dummy and cannot carry the dummy[3].

The test is held on a polished concrete floor. If a candidate pulls vertically up on the harness with a force of 70 **lbs** what horizontal pull force must the candidate apply in order to get the dummy moving? The static friction

3. "Firefighter Physical Ability Test Candidate Orientation Guide" by Industrial/Organizational Solutions, Inc.

coefficient between cotton clothing and polished concrete is 0.5

The dummy will move if the candidate supplies anything more than the maximum static frictional force, so let's try to calculate that.

If a candidate pulls vertically up on the harness with a force of 70 **lbs** then the floor must provide a normal force of 100 **lbs** to support the dummy. Now that we have the friction coefficient and normal force we can calculate the maximum static frictional force.

\begin{equation*}

F^{max}_{f,s} = \mu_sF_N =0.5\cdot100\, \bold{lbs} = 50\, \bold{lbs}

\end{equation*}

After the dummy starts moving, what force is required to keep it moving if $\mu_k = 0.4$?

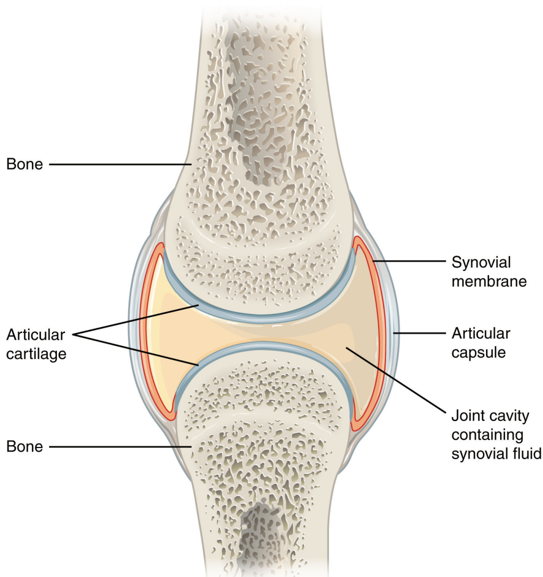
\begin{equation*}

F_{f,k} = \mu_kF_N =0.4\cdot100\, \bold{lbs} = 40\, \bold{lbs}

\end{equation*}

Synovial Joint Friction

Static and kinetic friction are both present in joints. Static friction must be overcome, by either muscle tension or gravity, in order to move. Once moving, kinetic friction acts to oppose motion, cause wear on joint surfaces, generate thermal energy, and make the body less efficient. (We will examine the efficiency of the body later in this textbook.) The body uses various methods to decrease friction in joints, including synovial fluid, which serves as a lubricant to decrease the friction coefficient between bone surfaces in synovial joints (the majority of joints in the body). Bone surfaces in synovial joints are also covered with a layer of articular cartilage which acts with the synovial fluid to reduce friction and provides something other than the bone surface to wear away over time[4].



Synovial joints allow for smooth movements between the adjacent bones. The joint is surrounded by an articular capsule that defines a joint cavity filled with synovial fluid. The articulating surfaces of the bones are covered by a thin layer of articular cartilage. Ligaments support the joint by holding the bones together and resisting excess or abnormal joint motions. Image Credit: OpenStax Anatomy & Physiology

4. OpenStax, Anatomy & Physiology. OpenStax CNX. Jun 25, 2018 http://cnx.org/contents/14fb4ad7-39a1-4eee-ab6e-3ef2482e3e22@10.1.

Check out the following lever simulation explore how force and distance from fulcrum each affect the equilibrium of the lever. This simulation includes the effects of friction, so you can see how kinetic friction works to stop motion and static friction contributes to maintaining static equilibrium.

An interactive or media element has been excluded from this version of the text. You can view it online here:
https://openoregon.pressbooks.pub/bpsupmat/?p=172

The equations given for static and kinetic friction are empirical models that describe the behavior of the forces of friction. While these formulas are very useful for practical purposes, they do not have the status of laws or principles. In fact, there are cases for which these equations are not even good approximations. For instance, neither formula is accurate for surfaces that are well lubricated or sliding at high speeds. Unless specified, we will not be concerned with these exceptions.[5]

5. OpenStax University Physics, University Physics Volume 1. OpenStax CNX. Aug 2, 2018 http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@11.1.

18. Equilibrium Torque and Tension in the Bicep*

Torque about the Elbow

So far we have used lever concepts and static equilibrium to solve for the forces in our forearm example. To gain a deeper understanding of why and how the effort and load forces depend on the effort arm and load arm distances, we need to study the concept of torque. We have already decided that the weight of the ball was pulling the forearm down and trying to rotate it around the elbow joint. When a force tends to start or stop rotating an object then we say the force is causing a torque (τ) . In our example, the weight of the ball is causing a torque on the forearm with the elbow joint as the pivot. The size of a torque depends on several things, including the distance from the pivot point to the force that is causing the torque.

Reinforcement Activity

The torque caused by a force depends on the distance that force acts from the pivot point. To feel this effect for yourself, try this:

Open a door by pushing perpendicular to the door near the handle, which is far from the pivot point at the hinges.

Now apply the same force perpendicular to the door, but right next to the hinges. Does the door open as easily as before, or did you have to push with greater force to make the door rotate?

One method to account for the effect of the distance to pivot when calculating the size of a torque you can first draw the line of action of the force, which just means to extend a line from both ends of the force arrow (vector) in both directions. Next you draw the shortest line that you can from the pivot point to the line of action of the force. This shortest line and the line of action of the force will always be at 90° to each other, so the shortest line is called the *perpendicular distance* ($d_{\perp}$). The perpendicular distance is also sometimes called the lever arm or *moment arm* or torque arm. We can draw these lines for our example problem:

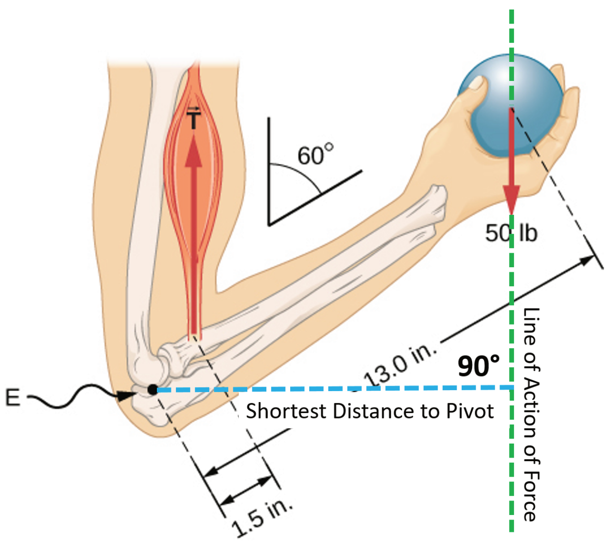


Diagram of the flexed arm showing the line of action of the gravitational force and the perpendicular distance from the pivot to the line of action. Image adapted from Openstax University Physics.

Finally, we can calculate the torque by multiplying the size of the force by the length of the lever arm ($Fd_{\perp}$) and that's it, you get the torque. In symbol form it looks like this:

\begin{equation}
torque = \tau = Fd_{\perp}
\end{equation}

Reinforcement Activity

If you hold your 0.65 **m** arm out horizontally with a 12 **lb** weight in your hand, what is the torque about your shoulder joint caused by the weight? Hint: If your arm is horizontal, and the weight points straight down, then what is the perpendicular distance from the joint to the weight?

After you have an answer, convert it from **N·m** to **ft·lbs** by using conversion factors between Newtons and pounds and feet and meters.

Rotational Equilibrium

The only time a torque won't cause an object to start or stop rotating is when it's cancelled out by other torques. This is exactly what is happening in our example problem, the torque caused by the bicep is counteracting the torque caused by the weight of the ball. When the torques cancel in this way, so that the net torque on the object is zero, the object is said to be in rotational equilibrium. In our example, the forearm is not starting to rotate (or stopping). Therefore the forearm is in rotational equilibrium so the net torque must be zero and that fact will allow us to find the bicep muscle tension. We have already stated that the forearm was not moving at all and that the net force so we can say the system is static equilibrium.

For an object to be in static equilibrium both the rotational and translational (linear) equilibrium conditions must be met. Writing these conditions on the torque and force in symbol form we have:

\begin{equation}
\tau_{net} = 0
\end{equation}

AND

\begin{equation}
F_{net} = 0
\end{equation}

Bicep Tension

The torques due to the bicep tension and the ball weight are trying to rotate the elbow in opposite directions, so if the forearm is in static equilibrium the two torques are equal in size they will cancel out and the net torque will be zero.

Looking at our equation for torque, we see that it only depends on the size of the force and the lever arm. That means that if the perpendicular distance to the bicep tension were 10x smaller than the distance to the center of the ball, the bicep tension force will have to be 10x times bigger than the weight of the ball in order to cause the same size torque and maintain rotational equilibrium. To find the bicep tension all we need to do now is determine how many times bigger the is the lever arm for the weight compared to the lever arm for the tension.

You might be thinking, *but we can't use this method, we don't know the perpendicular lengths, they aren't given, we only have the full distances from pivot to ball and pivot to bicep attachment.* Don't worry, if we draw a stick figure diagram we can see two triangles formed by the force action lines, the forearm and the perpendicular distances. The dashed (red) and solid (blue) triangles are similar triangles, which means that their respective sides have the same ratios of lengths.

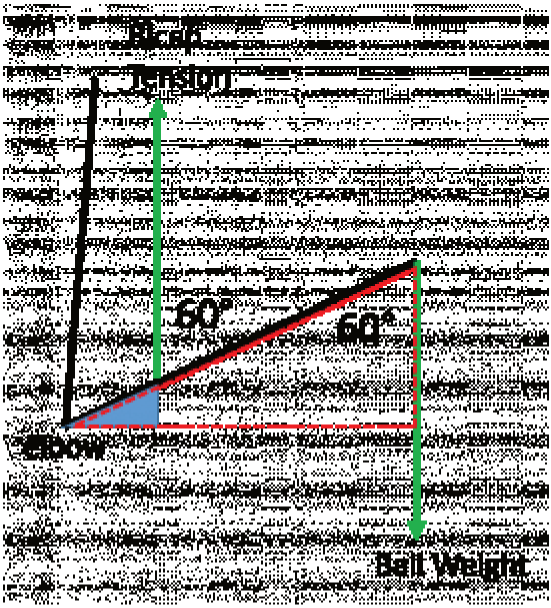


Diagram of the forearm as a lever, showing the similar triangles formed by parts of the forearm as it moves from 90 degrees to 60 degrees from horizontal. The hypotenuse (long side) of the smaller blue triangle is the effort arm and the hypotenuse of the larger dashed red triangle is the load arm. The vertical sides of the triangles are the distances moved by the effort (blue) and the load (dashed red)

The lengths of the long sides of the triangles are 13.0 **in** and 1.5 **in.** Taking the ratio (dividing 13.0 by 1.5) we find that 13.0 **in** is 8.667x longer than 1.5 **in**. The bottom side of the small (solid) triangle must also be 8.667x smaller than the bottom side of the big one (dashed). That means that the lever arm for the bicep is 8.667x smaller than for the weight and so we know the bicep tension must be 8.667x bigger than the weight of the ball to maintain rotational equilibrium.

The ball weight is 50 **lbs**, so the bicep tension must be:

\begin{equation*}
8.667 \times 50\, \bold{lbs} = 433\,\bold{lbs}
\end{equation*}

We've done it! Our result of 433 **lbs** seems surprisingly large, but we will see that forces even larger than this are common in the muscles, joints, and tendons of the body.

Symbol Form

Do you want to see everything we just did to calculate the tension in symbol form? Well, here you go:

The size of the torque due to the ball weight should be the tension multiplied by perpendicular distance to the ball:

\begin{equation*}
\tau_g = F_g \cdot d_{\perp, B}
\end{equation*}

The size of the torque due to the bicep tension should be the tension multiplied by perpendicular distance to the bicep attachment:

\begin{equation*}
\tau_T = T \cdot d_{\perp, T}
\end{equation*}

In order for net torque to be zero, these toques must be equal in size:

\begin{equation*}
T \cdot d_{\perp, T}= F_g \cdot d_{\perp, B}
\end{equation*}

We want the tension, so we divide both sides by $d_{\perp, T}$:

\begin{equation*}
T = \frac{F_g \cdot d_{\perp, B}}{d_{\perp, T}}

\end{equation*}

From the similar triangles we know that the ratio of perpendicular distances is the same as the ratio of the triangles' long sides:

\begin{equation*}

\frac{d_\{perp, B}}{d_{\perp, T}} = \frac{13.0\, \cancel{\bold{in}}}{1.5\, \cancel{\bold{in}}}= 8.667

\end{equation*}

Finally we find the tension:

\begin{equation*}

8.667 \times 50\, \bold{lbs} = 433\,\bold{lbs}

\end{equation*}

19. Alternative Method for Calculating Torque and Tension*

If you would rather not think about finding lever arms, you can instead calculate the size of thetorque as the size of the force multiplied by the full distance to the pivot, and by the sine of the angle between the force and that full distance. Written in equation form it looks like this:

\begin{equation}
torque = \tau = F \cdot d \cdot sin\theta
\end{equation}

Reinforcement Activity

The torque caused by a force depends on the angle between the line of action of the force acts and the line from where the force is applied to the pivot point. To feel this effect for yourself, try this:

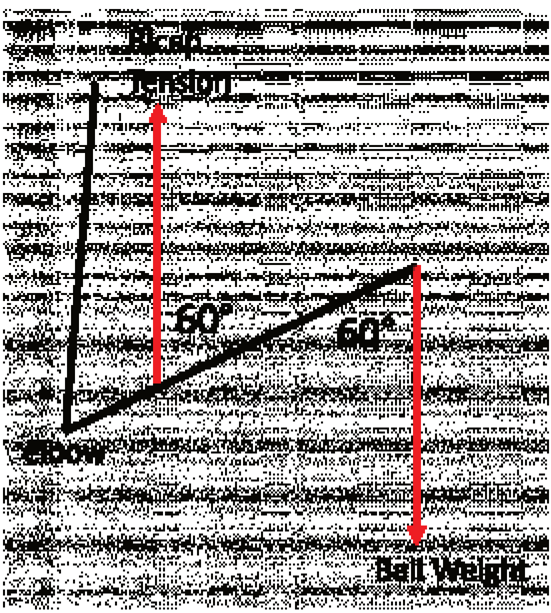
Rotate a door by pushing at 90° to the door right at the outer edge.

Now apply the same force on the door, still on the very edge, but instead of pushing in a direction 90° to the door, push along the door, straight in toward the hinges. Does the door swing as it did before?

In the second case, the angle between the force direction and the distance to the pivot was 0° (they were parallel).

Use the previous equation to show that t*he torque must be zero any time the line of action of the force goes straight through the rotation point (pivot).*

Now, we know the force is 50 **lbs**, the distance from the pivot to the weight is 13.0 **in** length of the forearm and from the diagram we see the angle between the weight of the ball and the forearm distance is 60**°** (the same as the bicep-forearm angle because they are alternate interior angles). This is easier to see if we draw a stick figure diagram:



Stick diagram of a flexed arm holding a ball showing the bicep tension and weight and the angles between the forces and the forearm.

Now we can calculate the torque due to the ball weight τ_b as:

\begin{equation*}
\tau_b = F \cdot d \cdot sin\theta
\end{equation*}
\begin{equation*}
= 50\, \bold{lbs} \cdot 13\, \bold{in} \cdot sin(60\bold{\degree})
\end{equation*}
\begin{equation*}
= 563\, \bold{in}\cdot\bold{lbs}
\end{equation*}

We have calculated the torque on the forearm due to the weight of the ball. You may be used to hearing about torque in $\bold{ft}\cdot\bold{lbs}$ rather than $\bold{in}\cdot\bold{lbs}$, but we can always convert units later if we desire. For now, let's keep working on finding the muscle tension.

We already know the torque due to the weight of the ball is $563\, \bold{in}\cdot\bold{lbs}$ so we just need to make sure that the tension in the biceps is large enough to cause the same torque even though it acts closer to the pivot. The biceps muscle torque, τ_{m} is:

\begin{equation*}
\tau_m = T \cdot d \cdot sin\theta
\end{equation*}

We just need to make this equal to the ball-weight-torque:

\begin{equation*}
T \cdot d \cdot sin\theta = 563\, \bold{in}\cdot\bold{lbs}
\end{equation*}

Then we divide both sides by d and $sin\theta$ to isolate the bicep tension:

\begin{equation*}
T = \frac{563\, \bold{in}\cdot\bold{lbs}}{d \cdot sin\theta}
\end{equation*}

Finally we put in our values for d and θ. Our original diagram gave us the distance as from bicep attachment to the pivot as 1.5 **in** and from our stick diagram we can see that the angle between the biceps tension and the distance is $180° - 60° = 120°$. We are ready to find the biceps tension value.

\begin{equation*}

T = \frac{563\, \cancel{\bold{in}}\cdot\bold{lbs}}{1.5\,\cancel{\bold{in}} \cdot sin(120\bold{\degree})}

\end{equation*}

\begin{equation*}

T = 433\,\bold{lbs}

\end{equation*}

Our result of 433 **lbs** seems surprisingly large, but we will see that forces even larger than this are common in the muscles, joints, and tendons of the body.

20. Unit 6 Review

Key Takeaways

Lever Arm

Effort Arm

Resistance (Load) Arm

Fulcrum

Pivot

Lever Classes

Mechanical Advantage

Range of Motion

Static Equilibrium

Friction

Coefficient of friction

Reactive forces

Learner Objectives

1. Identify tension, gravity, normal, and friction forces.[2]
2. Identify classes of levers and explain advantages

and disadvantages of each in terms of mechanical advantage and range of motion.[2]

3. Apply lever and equilibrium concepts to solve for forces and find mechanical advantage in scenarios involving levers. [3]
4. Apply normal force and friction coefficient concepts to calculate static and kinetic frictional forces.[3]

21. 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

The human body typically operates in 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 commonly 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 accentuated idea of how much actual work

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

is required for humans to stay upright. Toddlers are especially unstable due to their disproportionately massive heads, and after this unit we will understand why that feature so greatly affects their stability.

22. Unit 6 Practice and Assessment

Outcome 1

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

- A car hanging from a crane (there are two forces).
- A car skidding to a stop (there are three forces).
- 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).

2) A person stands on a scale. What type of force is pulling them down? What type of force is provided by the scale to hold them up?

Outcome 2

4) Consider the following items:

- Pliers
- Tweezers
- Shovel

(a) For each case, draw a stick figure of the tool and label the fulcrum, effort, load, effort arm, and load arm.
(b) State the class of lever for each item above.

(c) For each item above, state whether the tool is providing mechanical advantage or increasing range of motion.

Outcome 3

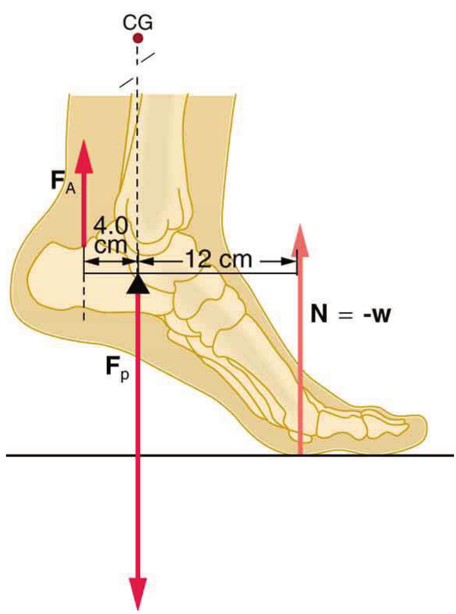
5) When a person raises their heels off the ground, the foot acts like a lever.

(a) Typically we consider the foot as a second class lever, but if we treat the ankle bone as the fulcrum, the tension in the calf muscle as the effort, and the normal force from the floor as the resistance, what class of lever is this system?

(b) Calculate the tension applied by the calf muscles (F_A) to lift a person with weight of 637 **N**.

(c) Calculate the force in the ankle joint between the foot and the lower leg bones (F_P). [*Hint: Both the normal force from the floor and the calf tension point upward. In order for the foot to be in static equilibrium, the force of the lower leg pushing down on the foot must cancel out both of those upward forces.*]

(d) Convert your final answers to pounds.



The foot acting as a lever arm. Image Credit: OpenStax College Physics

1

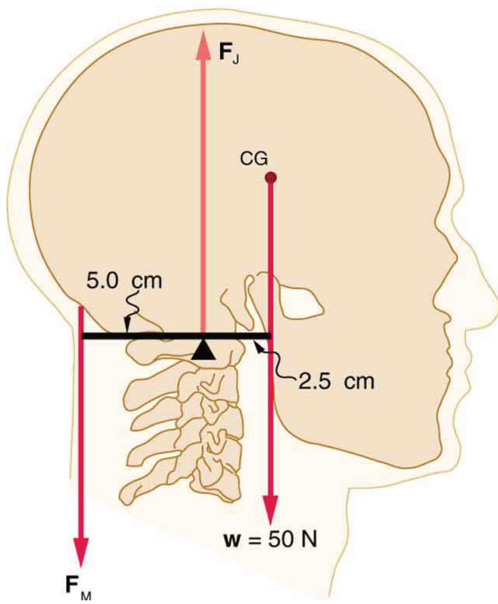
6) The head and neck are also a lever system.

(a) State the class of this lever system.

(b) Calculate the force of tension in the neck muscles (F_M) to hold the head in the position shown in the diagram.

(c) Calculate the force on the head-neck joint (F_J).

(d) Convert your final answers to pounds.



The head and neck acting as a lever system.Image Credit: OpenStax College Physics

1. OpenStax, College Physics. OpenStax CNX. Aug 3, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@11.42

[2]

Outcome 4

7) Find a value for the kinetic coefficient of friction between ends of a bone in a synovial joint lubricated by synovial fluid. State your source.

8) If the normal force between bones in the knee is 160 **lbs**, what is the kinetic frictional force between the surfaces of the knee bones?

9) A car with 10,000 **N** weight is sitting on concrete with the parking brake on,

a) What is the normal force on the car from the concrete? [Hint: Is the car in static equilibrium?]

b) What is the maximum horizontal force that can be applied before the car begins to skid? List your sources for the friction coefficient.

c) After the car begins to skid, how much force is required to keep it moving at constant speed, despite friction?

d) If you apply only 120 **N** of horizontal force to the stationary car, what is the static frictional force at that time?

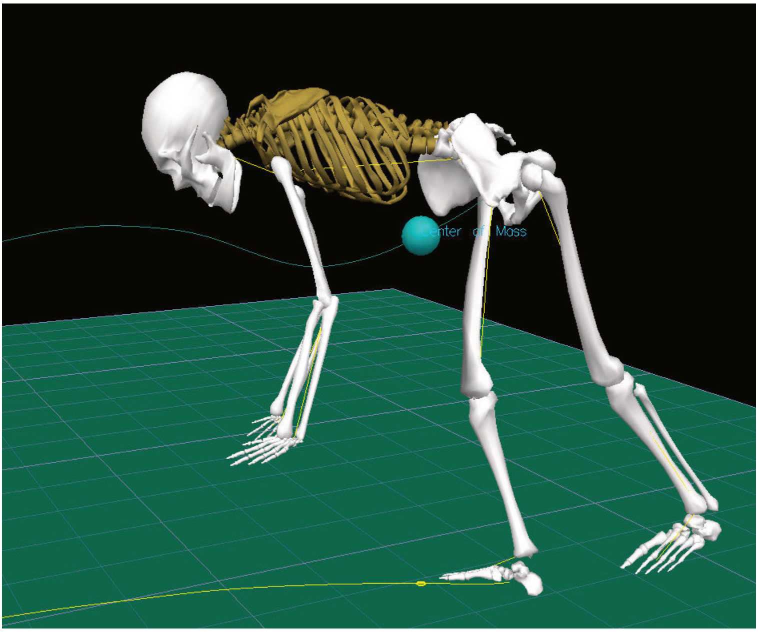
2. OpenStax, College Physics. OpenStax CNX. Aug 3, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@11.42

23. 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.

A YouTube element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bpsupmat/?p=122

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 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

1

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

https://youtube/DY3LYQv22qY

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

24. Supporting the Body

Support Force (Normal Force)

When standing on the ground gravity is pulling you down, but you aren't falling. The ground must be providing a supporting force that balances your weight to hold you in place. 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.

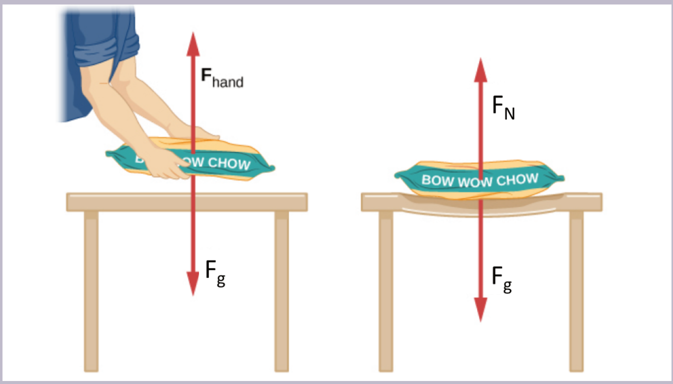
That's the normal force.

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.

http://cnx.org/contents/d50f6e32-0fda-46ef-a362-9bd36ca7c97d@10.18



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

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 Master Sgt. Sangster is also pushing down on the drill. The normal force on Master Sgt. Sangster's feet is less than her weight

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

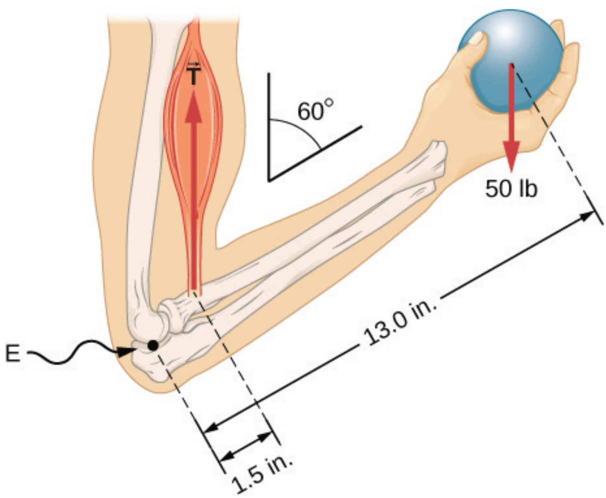
because she is also receiving an upward normal force from the drill handle.

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.

25. Tipping Point

Torque

When you hold an object in your hand, the weight of the object tends to cause a rotation of the forearm with the elbow joint acting as the pivot. The tension force applied by your biceps tries to counteract this rotation.



The elbow joint flexed to form a 60° angle between the upper arm and forearm while the hand holds a 50 ***lb*** *ball. The weight of the ball exerts a torque on the forearm about the elbow joint. Image Credit: Openstax University Physics*

[1]

When forces applied to an object tend to cause rotation of the object, we say the force is causing a torque. The size of a torque depends on the size of the force, the direction of the force, and the distance from the pivot point to where the force acts.

Reinforcement Activity

The torque caused by a force depends on the distance that force acts from the pivot point. To feel this effect for yourself, try this:

Open a door by pushing perpendicular to the door near the handle, which is far from the pivot point at the hinges.

Now apply the same force perpendicular to the door, but right next to the hinges.

Does the door rotate open just as it did before, or did you have to push with greater force to make the door rotate?

Rotational Equilibrium

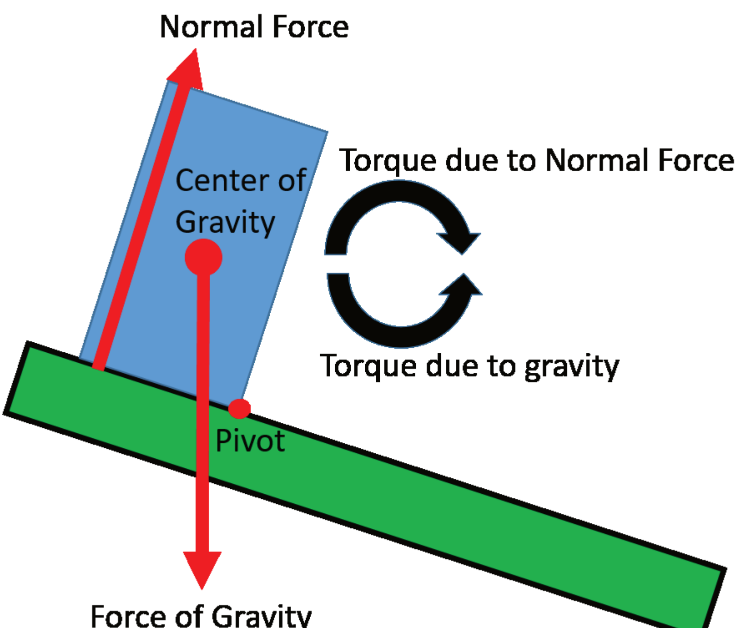
The only time a torque wont cause an object to start or stop rotating is when its cancelled out (balanced) by other torques, as we saw for the torque due to biceps tension and torque due to ball weight

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

in the forearm example. When the torques all cancel out the net torque is zero and the object must be in rotational equilibrium. An object in rotational equilibrium might be rotating, but it won't change it's rotation speed or direction. If an object in rotational equilibrium is not rotating then it will not start rotating as long as it remains in rotational equilibrium.

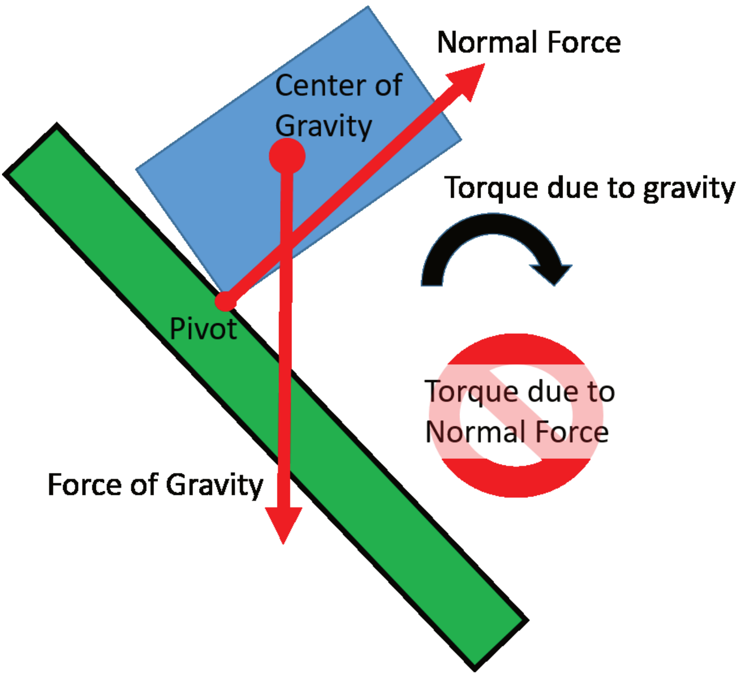
Tipping Point

When a body's center of gravity is above the area formed by the support base the normal force can provide the torque necessary to remain in rotational equilibrium.



An object in rotational equilibrium. The torque from normal force cancels the torque from gravity.

The critical tipping point is reached when the center of gravity passes outside of the support base. Beyond the tipping point, gravity causes rotation away from the support base, so there is no normal force available to cause the torque needed to cancel out the torque caused by gravity. The normal force acting on the pivot point can help support the object's weight, but it can't create a torque because it's not applied at any distance away from the pivot.



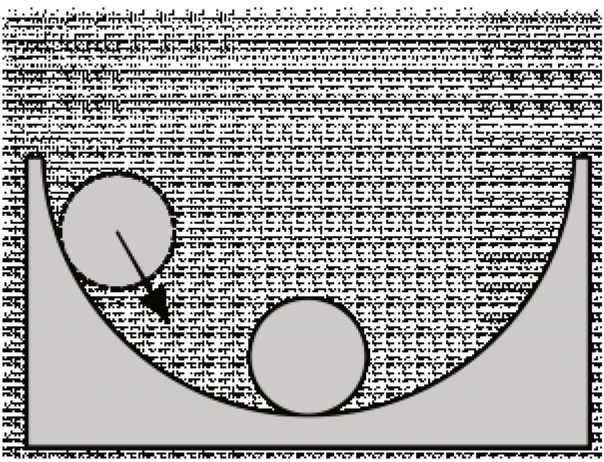
An object out of rotational equilibrium. The normal force acting at the pivot cannot produce a torque to cancel the torque caused by gravity.

Now with a net torque the object can not be in rotational equilibrium. The object will rotate around the edge of the support base and tip over. We often refer to structures (and bodies) that are resistant to tipping over as having greater stability.

26. Types of Equilibrium

Stable Equilibrium

If a structure is pushed out of equilibrium we say it has been displaced from equilibrium. If the object tends to move back toward its equilibrium position then it must be in a region of stable equilibrium and the force that pushed it back is a restoring force.



A marble in the bottom of a bowl is an example of stable equilibrium. Image credit:

1

As your arm hangs from your shoulder, it is in stable equilibrium.

1. "Stable Equilibrium" by Urutseg, Wikimedia Commons is in the Public Domain, CC0

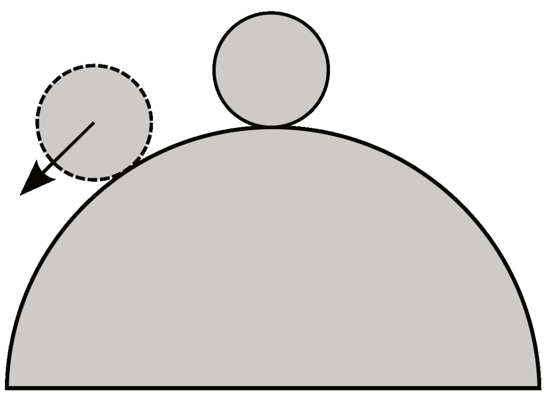
If your arm is lifted to the side and then let go it will fall back down to the hanging position. The hanging arm is a stable position because the center of gravity of the arm is located below the base of support, in this case the shoulder. When displaced (lifted a bit) the force of gravity acting on your arm will cause a torque that rotates your arm back down to the hanging position. In such cases, when an object is displaced from the equilibrium position and the resulting net forces (or torques they cause) move the object back toward the equilibrium position then these forces are called restoring forces. The sloth takes advantage of stable equilibrium to save energy that humans spend on staying upright. If the sloth is displaced in any direction, the force of gravity automatically acts as a restoring force and returns the slot to its equilibrium position.

A two-toed sloth hangs from its feet in a stable equilibrium position. Image Credit: Cliff via Wikimedia Commons

[2]

Unstable Equilibrium

When a system in equilibrium is displaced and the resulting net force pushes the object even further away from the equilibrium position then it must have been in an unstable equilibrium. Technically, real systems cannot spend time at unstable equilibrium point because the tiniest vibration will cause them to move out of equilibrium not to mention that you could never place them perfectly into position in the first place. Trying to balance a marble on a hill is a good example:



An example of unstable equilibrium is a marble placed on a hill. Image Credit: "Unstable Equilibrium" by Urutseg, via Wikimedia Commons.

2. By Cliff (Flickr: Two Toed Sloth (Choloepus didactylus)) [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons

3

Metastable Equilibrium

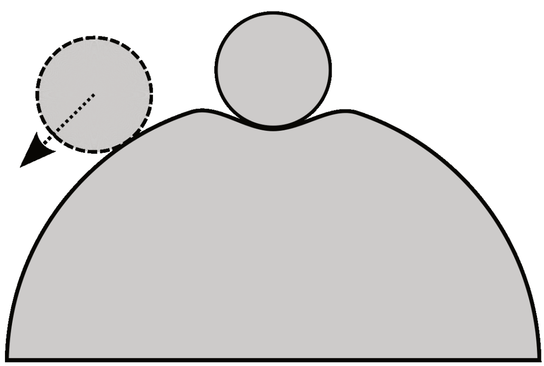
A person in a barely-stable equilibrium. Image Credit: Usien via Wikimedia Commons.

4

Some structures that are in stable equilibrium can be displaced

3. "Unstable Equilibrium" by Urutseg, Wikimedia Commons is in the Public Domain, CC0
4. By Usien [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)], from Wikimedia Commons

relatively far before they are no longer in equilibrium compared to other structures that only require a small displacement to move out of equilibrium. We often call these systems stable and unstable, but this can be misleading because any standing structure is somewhat stable and a truly unstable structure would not stand still for any time. For example we expect that most people would say the person balancing on their head in the image above is unstable. However, they are actively adjusting the shape of their body to shift their center of gravityand to remain within a region of stable equilibrium and not pass a tipping point. We could say that this person is in a very narrow metastable equilibrium. Keeping your balance as you stand, sit, or walk is an act of maintaining metastable equilibrium.



The marble is in meta-stable equilibrium as long as it doesn't move outside the dip in the center. The peak at edge of the dip is analogous to the tipping point for a structure; beyond this point the marble will not move back toward the equilibrium position. Image credit: "Meta-stable Equilibrium" by Urutseg via Wikimedia Commons

[5]

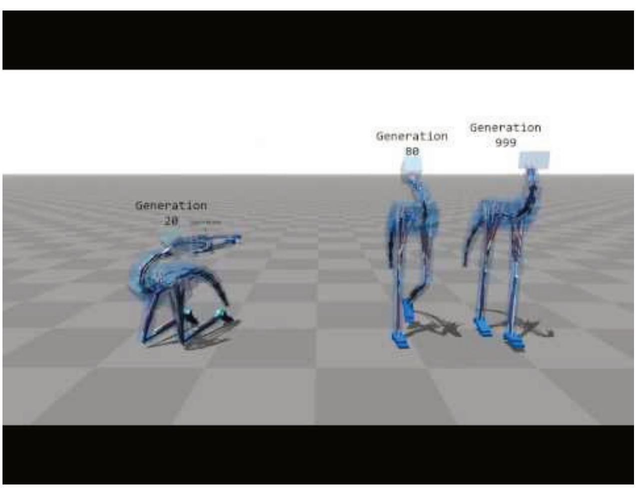
5. "Meta-stable Equilibrium" by Urutseg, Wikimedia Commons is in the Public Domain, CC0

27. Walking and Tripping

For humans walking is an act of moving in and out of metastable equilibrium.

1. You lean forward and your center of gravity passes the tipping point, which moves you out of metastable equilibrium.
2. You take a step to move your support base back underneath your center of gravity, putting you back into metastable equilibrium.
3. Repeat.

When your foot doesn't correctly move forward then you remain out of metastable equilibrium and fall over. We call that process tripping. Check you these AI simulations of creature that employ bipedal motion learning how to walk, and tripping along the way.

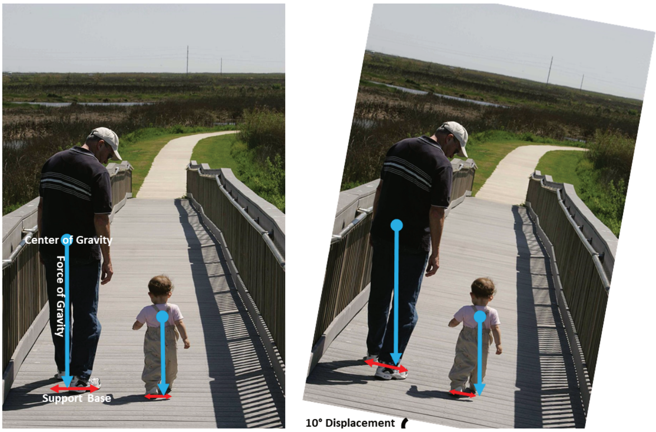


A YouTube element has been excluded from this version of the *text. You can view it online here: https://openoregon.pressbooks.pub/bpsupmat/?p=139*

To see what AI algorithms can do when given a real physical body to experiment with, check out these robots.

28. Human Stability

When asking what makes a structure more or less stable, we find that a high center of gravity or a small support base makes a structure less stable. In these cases a small displacement is need in order to move the center of gravity outside the area of support. Structures with a low center of gravity compared to the size of the support area are more stable. One way to visualize stability is to imagine displacement of the center of gravity caused by placing the object on a slope. For example, a 10**°** displacement angle might displace the center of gravity of a toddler beyond the support base formed by its feet, while an adult would still be in equilibrium.



Compared to an adult, a smaller displacement will move a toddlers center of gravity outside the base of support. Image adapted from A man and a toddler take a leisurely walk on a boardwalk by Steve Hillibrand via Wikimedia Commons.

1

1. " A man and toddler take a leisurely walk on a boardwalk" by Steve

The center of gravity of a person's body is above the pivots in the hips, which is relatively high compared to the size of the support base formed by the feet, so displacements must be quickly controlled. This control is a nervous system function that is developed when we learn to hold our bodies erect as infants. For increased stability while standing, the feet should be spread apart, giving a larger base of support. Stability is also increased by bending the knees, which lowers the center of gravity toward the base of support. A cane, a crutch, or a walker increases the stability of the user by widening the base of support. Due to their disproportionately large heads, young children have their center of gravity between the shoulders, rather than down near the hips, which decreases their stability and increases the likelihood of reaching a tipping point.[2]

Hillebrand, U.S. Fish and Wildlife Service, Wikimedia Commons, is in the Public Domain

2. OpenStax, College Physics. OpenStax CNX. Aug 3, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@12.1.

Warning label on a bucket indicating the danger of children falling into a bucket and drowning. This danger is caused by the inherent instability of the toddler body. Image Credit: GodsMoon via Wikimedia Commons.

3

3. "Drowning Child Warning" by GodsMoon, Wikimedia Commons is licensed under CC BY-SA 2.0

29. The Anti-Gravity Lean

GIF animation of the "anti-gravity lean" maneuver in which a person wearing shoes that attach to the floor can lean forward with straight legs and then return to a standing position. Image Credit: Asanagi via Wikimedia Commons

[1]

The structures discussed in the previous chapters were resting on the support base, which was not *attached* to the support surface (such as your feet and the ground). Therefore only normal force was available to cancel torques caused by gravity and maintain equilibrium. When the support base is attached then tension can help cancel out gravitational torques and the structure can remain in equilibrium even when the center of gravity moves outside the area of support. Such structures are known as cantilevered structures. The animation above shows someone performing the "anti-gravity lean" during which the body is momentarily a cantilevered structure. The maneuver requires that the heels of the shoes be attached to the ground in order to provide a tension force. Cantilevered structures can generate especially large stress and strain on the materials in the structure, for example the Achilles' tendon is severely stressed during the anti-gravity lean. When stress becomes too great then rupture may occur. In a future unit we will examine response of body tissues to stress, such as deforming and rupturing.

1. "Anti-gravity Lean" by Asanagi, Wikimedia Commons

30. Unit 5 Review

Key Terms and Conepts

Center of Gravity

Normal Force

Torque

Rotational Equilibrium

Stable Equilibrium

Unstable Equilibrium

Metastable Equilibrium

Stability

Learner Objectives

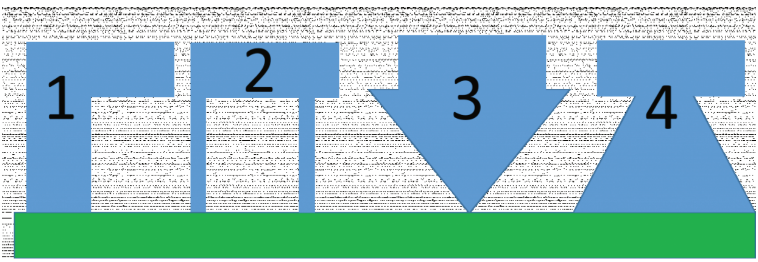
1. Define center of gravity, support base, and normal force.[2]
2. Compare the relative torque applied to objects by various forces.[2]
3. State the conditions for static equilibrium.[2]
4. Compare and contrast stable, unstable, and metastable equilibrium.[2]
5. Apply center of gravity, support base, and

metastable equilibrium concepts to compare the stability of various structures.[2]

31. Unit 5 Practice and Assessment

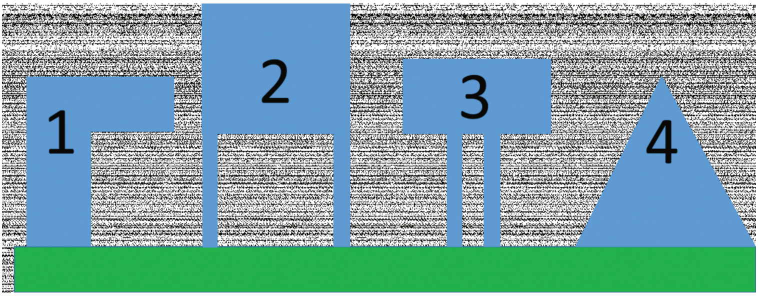
Outcome 1

1. Rank the structures below in order of increasing support base width.



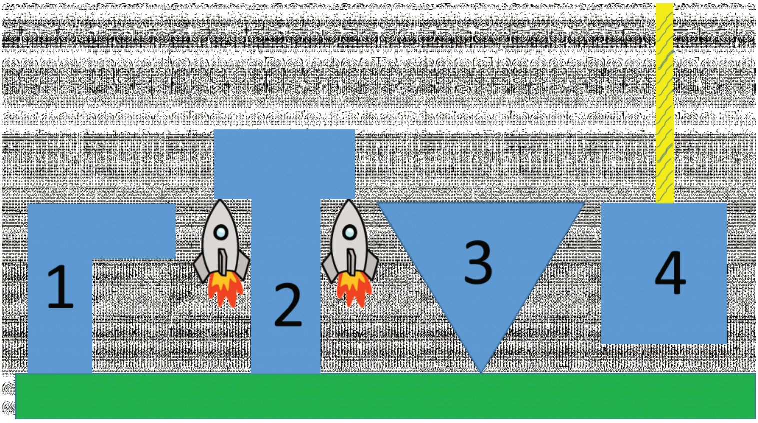
Four structures of equal height, but varying shape and base width.

2. Rank the structures below in order of increasing center of gravity height. All four structures are solid and are made of the same material.



Four structures of equal mass, but varying height and base width.

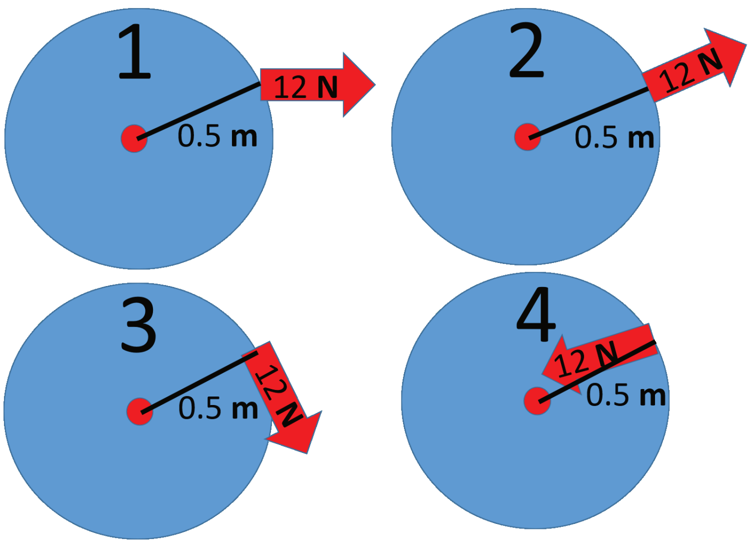
3. Rank the structures below in order of increasing normal force from the ground. All four structures have the same weight and are at rest.



Four structures of equal weight. The second structure has rockets pushing up on it and the fourth structure is hanging from a rope. Rocket images from http://wpclipart.com are in the Public Domain.

Outcome 2

4. A child at a playground pushes on a large disk that rotates on an axle trough its center. The child tries pushing on the edge of the disk in several different directions, as indicated by the top-down diagrams below. Rank the child's attempts by the amount of torque applied to the disk, from least to greatest.

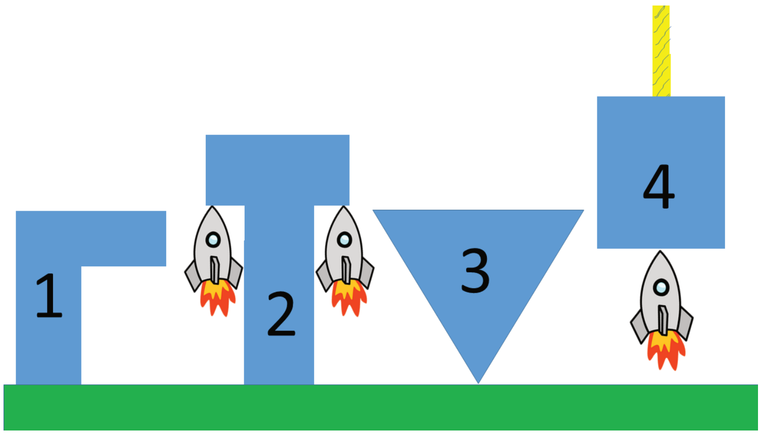


Four disks 0.5 m radius, each with a 12 N force applied at the edge. Disk 1 has the force applied outward at a slight angle to the radius. Disk two has the force applied outward directly along the radius. Disk 3 has the force applied perpendicular to the radius. Disk four has the force applied at a slight angle to the radius, but inward. The angle with the radius is smaller than the angle in disk 1.

5. If the child in the previous problem was able to apply a 12 **N** force and the disk had a 0.5 **m** radius, what would be the value of the torque applied in trial 3?

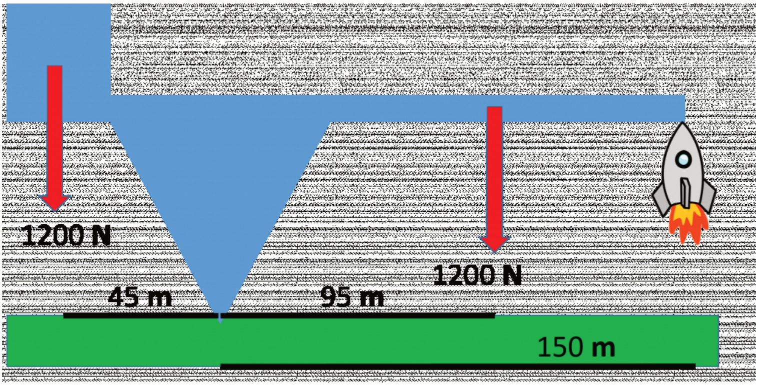
Outcome 3

6. Each structure in the following image is at rest. What do you know about the net force on each block?



Four structures of equal weight. The second structure has rockets pushing up on it and the fourth structure is hanging from a rope. Rocket images from http://wpclipart.com are in the Public Domain.

7. Structure #1 weighs 5000 **N**. What is the normal force on the structure?
8. Structure # 2 weighs 5000 **N**. Each rocket is capable of pushing with 1000 **N** of force. What is the normal force on the structure from the ground?
9. Structure # 4 weighs 5000 **N**. Each rocket is capable of pushing with 1000 **N** of force. What is the tension force provided by the rope?
10. The structure in the following image is at rest. What do you know about the net torque on the structure?

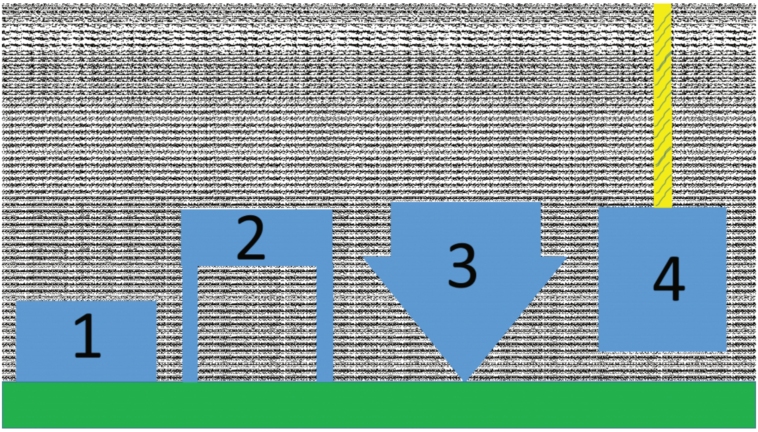


An inverted triangular structure at rest with a block weighting one side, an arm weighting the other, and a rocket pushing up on the arm. Rocket images from http://wpclipart.com are in the Public Domain.

11. An engineer performing an inspection on the previous structure measures 45 **m** from beneath the center of gravity of the block to the point where the structure contacts the ground. The block weighs 1200 **N**. She then measures the distance to the beneath the center of gravity of the arm to be 95 **m**. The arm weighs 1200 **N** as well. Finally she measures the distance to beneath the rocket to be 150 **m** from the contact point. She then calculates the force being provided by the rocket, what value does she get?

Outcome 4

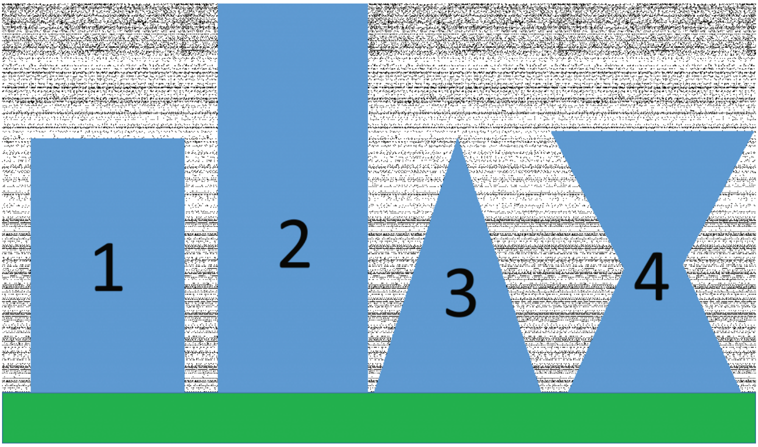
12. State which type of equilibrium is exhibited by each structure below: stable, unstable, or metastable.



Four structures in static equilibrium

Outcome 5

13. Rank the structures below in order of increasing stability. All structures are solid and made of a single material type.

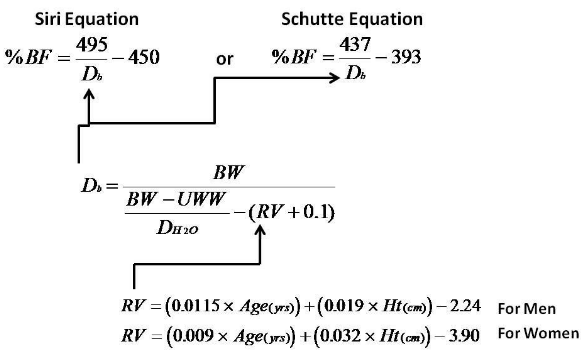


Four structures in metastable equilibrium.

32. Body Density

Body Fat Percentage from Body Density

The pitfalls of the previously discussed skinfold method and the BMI can be somewhat avoided by actually measuring body density for use in empirical formulas that approximate body fat percentage:



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

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

been developed for different population sets in an effort to increase accuracy.[2].

Body Density

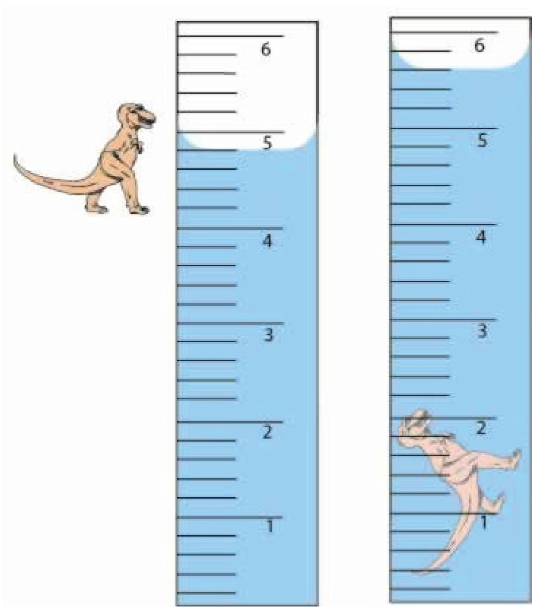
In order to understand density and how it might be measured, we need to know that ***volume*** (V) is the amount of space taken up by an object and ***mass*** (m) is a measure of the amount of matter contained in the object. For the body and other everyday objects matter refers to the atoms that make up the object and the number and type of atoms determines the mass. Later we will see that mass plays an important role in determining the weight and motion of objects. The SI units for volume and mass are cubic meters ($\mathbf{m^3}$) 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/m³*** *button* to see the values in SI units).

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 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.

2. "Under Water Weighing" by University of Vermont College of Medicine, Department of Nutrition and Food Science,

33. Body Volume by Displacement (Dunking) Method

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]

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 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

1. "Density Using Displacement" by Greg Golz, https://sites.google.com/site/sciencegolz/ is licensed under CC BY 4.0
2. "Bod Pod Services" by Oregon Clinical & Translational Research Institute, Oregon Health Sciences University.

[3]

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

34. Body Weight

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 Activity

Draw a picture of yourself jumping on a trampoline (a stick figure will work). Then add an arrow representing gravity acting on you while you are in the air. The arrows should start at your center and point in the direction that the force is pushing or pulling you. Label the forces arrows.

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

35. 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.

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-keuken weegschaal1284" by Algont via wikimedia commons.

1

Mass can be determined from a weight because weight is just the

1. "Digi-keukenweegschaal1284" by Algont [CC BY-SA 3.0

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:

\begin{equation}

Force\, of\, gravity = mass\, \times \, \right(acceleration\, due\, to\, gravity\left)

\end{equation}

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

Reinforcement Exercise

In 2016 Helen Maroulis became the first American woman to win an Olympic gold medal in wrestling. She competes in the 53 **kg** class, which most people call her weight class. However, 53 **kg** is not actually a weight, it's a mass. Use the formula provided above to calculate Helen's weight in Newtons.

Find a conversion factor between Newtons and pounds and convert Helen's competition weight to **lbs**.

(http://creativecommons.org/licenses/by-sa/3.0/)] via wikimedia commons.

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

Reinforcement Exercises

A person weighs 902 **N** (203 **lbs**) What is the persons mass? (Assume they are on Earth's surface)

The same person displaces 0.089 $\mathbf{m^3}$ of water volume when fully submerged. What is the body density of the person?

Body Weight and Mass on the Moon

The value of g only holds constant near the surface of the Earth, and therefore scales that 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 you are not near the surface of the Earth then use the Universal Law of Gravitation.

A YouTube element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bpsupmat/?p=101

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 $6.67408 \times 10^{-11} \frac{\bold{m^3}}{\bold{ kg^1 s^2}}$. Written in equation form the universal law of gravitation is:

\begin{equation}
$F_g = G\frac{m_1 m_2}{r^2}
\end{equation}

Reinforcement Exercise

Look up the mass and radius of the Earth and enter these into the Universal Law of Gravitation along with the value for G provided earlier. Use the mass of the Earth as m_1 so m_2 is the only thing left unknown in the equation. Multiply and divide everything other than m_2 as indicated by the equation to get m_2 multiplied by a single number. What number did you find should be multiplied by an object's mass to find the force of gravity? How does the resulting equation compare to the equation for the force of gravity near the surface of Earth that we stated earlier?

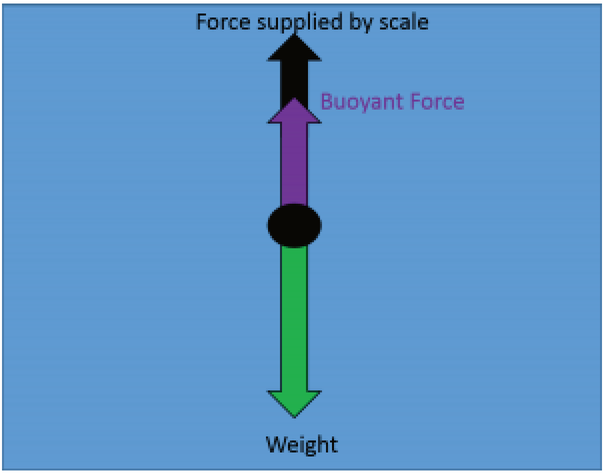
36. Under Water Weight

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 (apparent weight) must perfectly balance the weight of the object, as long as the person is holding still. We can use arrows (vectors) 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 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.

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.*

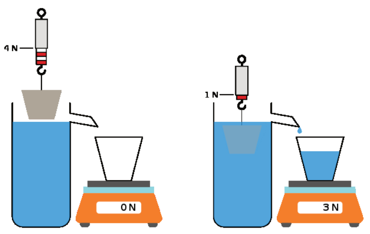
Reinforcement Exercises

Hold your hand under water. Now take an empty water bottle and try to hold it under water.

In which case is the total buoyant force larger? Use Archimedes' Principle to explain why.

1

Buoyant Force and Density



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*

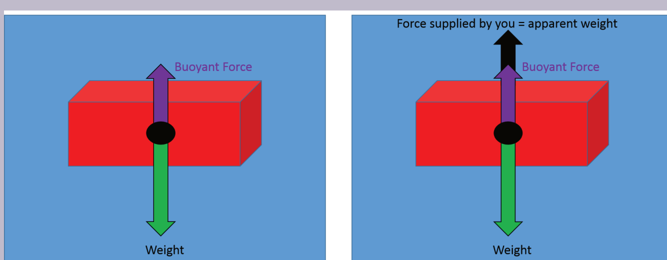
A given mass of low density tissue will take up volume relative to the same mass of high density tissue. Taking up the volume means more water is displaced when the body is submerged so the buoyant force will be larger compared to the weight than it would be for a more dense body. In turn, that means 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

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

determined. We will do that in the next chapter, but first we should become more familiar with the Buoyant force.

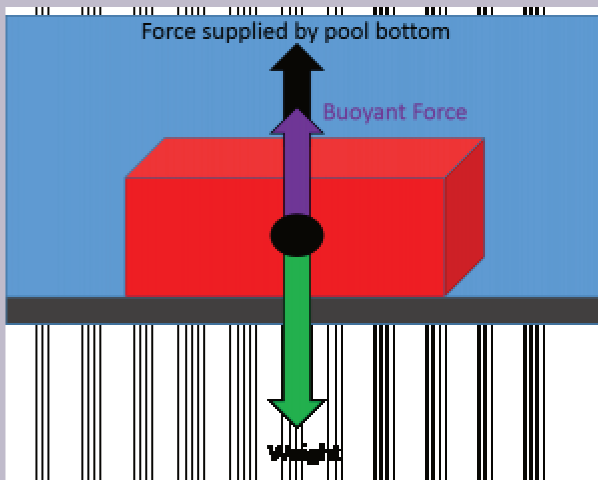
Everyday Example

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).



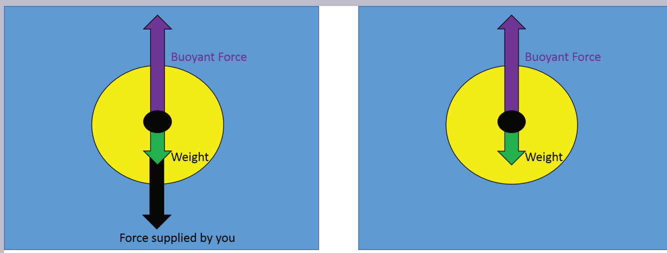
Free body diagrams for bricks in water. The brick on the left is sinking, the brick on the right is being held in place by you.

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.

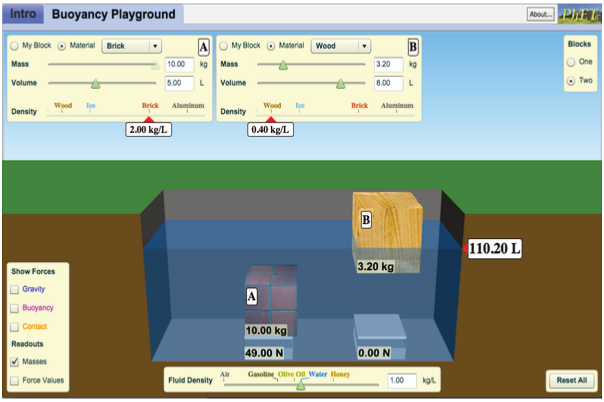
An iceberg floating with roughly 9/10 of its volume submerged. Image Credit: "Iceberg" created by Uwe Kils (iceberg) and User:Wiska Bodo (sky) via Wikimedia Commons

2

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

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

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



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

A YouTube element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bpsupmat/?p=109

37. Hydrostatic Weighing

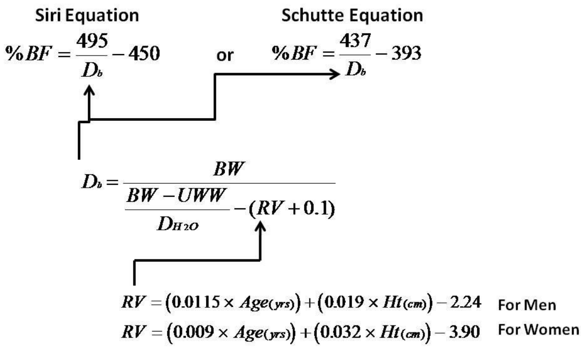
The method of hydrostatic weighing allows us to determine the average density (ρ) of a any object without any need for a volume (V) measurement by measuring only its weight (W_0) and apparent weight, also known as under water weight (UWW). To see how we arrive at this useful result, follow the steps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

\begin{equation}
\rho = \frac{W_O}{W_O-F_A}\rho_W
\end{equation}

Reinforcement Exercises

Calculate the density of an that object that weighs 12 **N**, but has an apparent weight of only 8.5 **N**.

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.



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]

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

\begin{equation*}
\rho = \frac{m_O}{V_O}
\end{equation*}

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

\begin{equation*}
m = \frac{W_O}{g}
\end{equation*}

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

\begin{equation*}
\rho = \frac{W_O}{gV_O}
\end{equation*}

For a completely submerged object the volume of water displaced

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

is equal to the volume of the object, so we can replace V_O with V_D.

\begin{equation*}

\rho = \frac{W_O}{gV_D}

\end{equation*}

Using the definition of density again, we can replace the volume of water displaced with the displaced water mass (m_W) divided by water density (ρ_W).

\begin{equation*}

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

\end{equation*}

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:

\begin{equation*}

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

\end{equation*}

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.

\begin{equation*}

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

\end{equation*}

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):

\begin{equation*}

F_B = W_O − F_A

\end{equation*}

Making that replacement in our density equation we have:

\begin{equation*}
\rho = \frac{W_O}{W_O-F_A}\rho_W
\end{equation*}
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.

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:
\begin{equation}
SG = \frac{\rho}{\rho_W} = \frac{W_O}{W_O-F_A}
\end{equation}

Reinforcement Exercises

Calculate the specific gravity of an that object that weighs 12 **N**, but has an apparent weight of only 8.5 **N**.

38. Unit 4 Review

Key Terms and Concepts

Mass

Volume

Density

Weight

Apparent Weight

Static Equilibrium

Net Force

Buoyant Force

Archimedes' Principle

Hydrostatic Weighing

Specific Gravity

Learner Outcomes

1. Define mass, volume, density, weight and apparent weight.[1]
2. Explain how mass and weight are related when near the surface of Earth and calculate one from the

other.[1,2]

3. Apply the concept of static equilibrium to determine the magnitude and direction of unknown forces.[3]
4. Apply Archimedes' principle to determine the buoyant force objects and decide if they will sink or float.[2]
5. Determine density from mass and volume measurements and via hydrostatic weighing.[4]

39. Body Mass Index

Body Composition

Body composition is just one of many measurable properties and factors that health professionals use to evaluate a person's health. 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 Mass Index

The body mass index (BMI) attempts to categorize body composition using only height and weight as inputs. Health professionals 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 more than typical muscle for a given height can result in a false unhealthy weight categorization. [2]. Additional methods for determining body composition include bioelectric impedance, anthropometric, DEXA scan, hydrostatic weighing, and

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

the skin fold method, which we will investigate in the following sections.[3]

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

40. 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?

Outcome 2

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

3) Convert your own weight from pounds to Newtons. 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. Based on your answers to the previous question, what would your weight be on the moon? What would your mass be on the moon?

Outcome 3

4) A 7 **N** force pushes on an object to the right and a 7 **N** force pushes on the object to the left. What is the net force? Can the object be in static equilibrium?

5) A 5 **N** force pushes on an object to the right and a 7 **N** force pushes on the object to the left. What is the net force? Can the object be in static equilibrium?

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

How large is the friction force? Draw a free body diagram of the situation.

7) Helping a 48 **lb** toddler learn to float in a swimming pool you notice that it feels as though they only weigh 5 **lbs**. How large is the buoyant force on the toddler? Draw a free body diagram of the situation.

Outcome 4

8) What weight of water must the toddler in the previous question be displacing?

9) An object has a volume of 0.5 $\mathbf{m^3}$. What is the maximum volume of water it can displace? What weight of water can it displace?

10) The object in the previous problem has a weight of 150 **N**. Will it float?

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

Outcome 5

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

12) An object has a weight of 5.5 **N** and an apparent weight of 3.5 **N** when fully submerged. Will the object float?

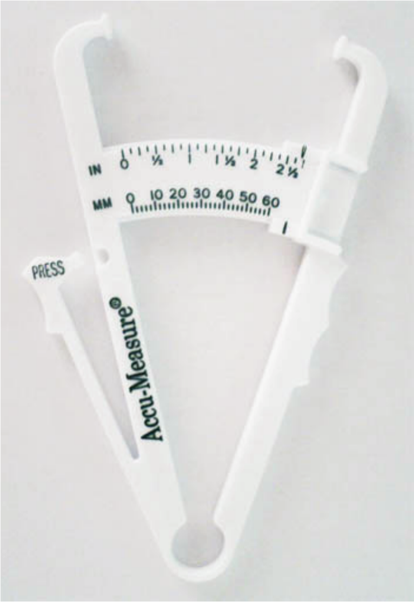
13) Calculate the density of the object in the previous problem.

41. 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 random error on 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 (uncertainty is typically 3**%** body fat[3]).

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

42. 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

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

mm, and 54 **mm** and he is uncertain of the actual value. He decides that because 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:

\begin{equation*}

Average\, PD = \frac{\left(56+57+54+56+55+57+58\right)\bold{mm}}{7} = 56.14\, \bold{mm}

\end{equation*}

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.

43. Working with Uncertainties*

The Certainty of Uncertainty

No measurement can be completely error free, infinitely precise, or perfectly accurate. Therefore we can never be absolutely certain of the actual value of a physical quantity we are attempting to measure. We can be certain that all measurement results have uncertainty associated with them. 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 in measured results so that it can be reported along with the results. In this textbook we will stick to the simple methods, if you decide to continue studying science you will learn some of the more sophisticated methods[1][2].

1. "Uncertainty in Measurement Results" by NIST Reference on Constants Units and Uncertainty, National Institute of Standards and Technology
2. "Experimental Uncertainty" by EngineerItProgram, California State University, Chio

Uncertainty in Tyler's Pupillary Distance Measurement

There are various statistical methods[3] 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 uncertainty in his measurement. 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.

\begin{equation*}

Average\, PD = \frac{\left(56+57+54+56+55+57+58\right)\bold{mm}}{7} = 56.14\, \bold{mm}

\end{equation*}

We will use 2 **mm** as a rough estimate of the uncertainty, which is probably an over-estimate, but it puts us on the safe-side so we don't underestimate the uncertainty. If we wanted to show the final result of Tyler's measurements including uncertainty in the standard way then we would write:

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

Notice that 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 accurately we know the result.

3. "Uncertainty in Measurement Results" by NIST Reference on Constants Units and Uncertainty, National Institute of Standards and Technology

Significant Figures

Special consideration is given to zeros when counting significant figures. The zeros in 0.053 are not significant, 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[4]. The table below will help you deal with zeros.

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 x 10^{3}	0	3

4. 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:

- $517\, \bold{m}$
- $0.00180\, \bold{mi}$
- $6700\, \bold{s}$

Reinforcement Activity

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

- $(517 \pm 20)\, \bold{m}$
- $(0.00180 \pm 0.00006)\, \bold{mi}$
- $(6700 \pm 2)\,\bold{s}$

Method of Significant Figures

Sometimes values are reported without uncertainty, but 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 has significant uncertainty. 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.* [5] 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 final answer should 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 final answer 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 to be: oranges

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

- 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.

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:

\begin{equation*}
Average\, PD = \frac{\left(56+57+54+56+55+57+58\right)\bold{mm}}{7} = 56.14\, \bold{mm}
\end{equation*}

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

\begin{equation*}
\left(56+57+54+56+55+57+58\right)\bold{mm} = 393\, \bold{mm}
\end{equation*}

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**. This result has more significant figures than the result we originally determined by 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 Activity

Let’s return to our everyday example of Ronnie estimating 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 4 times per week. We calculated his cost for gas during the 11 week term:

\begin{equation*}

11\,weeks \,per \, term =

=\left(\frac{11\, \cancel{weeks}}{1\, term} \right)

\left(\frac{4\, \cancel{trips}}{1\, \cancel{week}} \right)

\left(\frac{14.2\, \cancel{miles}}{1\, \cancel{trip}} \right)

\left(\frac{1\, \cancel{gallon}}{27\, \cancel{miles}} \right)

\left(\frac{2.86\, dollars}{1\, \cancel{gallon}} \right)

\end{equation*}

\begin{equation*}

=\bold{\$}66.18\, per\, term

\end{equation*}

Correct the result of this calculation to have the correct number of significant figures.

44. 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:

\begin{equation*}

\Average\, PD = 56\, \bold{mm}\, \pm\left(\frac{2\,\bold{mm}}{56\,\bold{mm}}\right)\times100=56\,\bold{mm}\pm 4\%

\end{equation*}

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].

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

45. 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]

46. Unit 3 Practice and Assessment

Outcomes 1, 2, 3

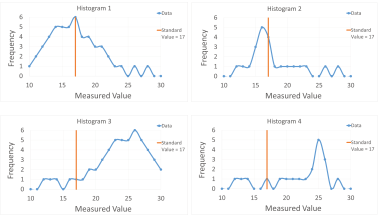
1. Would putting larger tires on a vehicle introduce random or systematic error into the speedometer reading? Would this affect the accuracy or precision (or both) of the speedometer? Explain your answers.

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.

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.



Histograms of values measured during an experiment.

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

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.

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

47. 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:

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

Jolene's Table of Possible Migraine Causes

Possible Cause	**Reasoning**	**Readily Testable?**
Dehydration	*she rarely had time to stop for water during shift*	Yes
~~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. One week she made sure to drink more water, the next week she made sure to go to bed and get up at the same time every day, and finally she made sure to have quick foods ready for breaks. Jolene repeated the cycle for nine 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	Total
Hydrated	24			26			21			
Consistent Sleep		18			20			19		
Well Fed			23			27			25	

Reinforcement Activity

Finish analyzing Jolene's data by adding up the pain values for each test condition and filling in the total column on the right. Based on the results of Jolene's test, what conclusion do you make about which variable is most likely making the largest contribution to her migraines?

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.

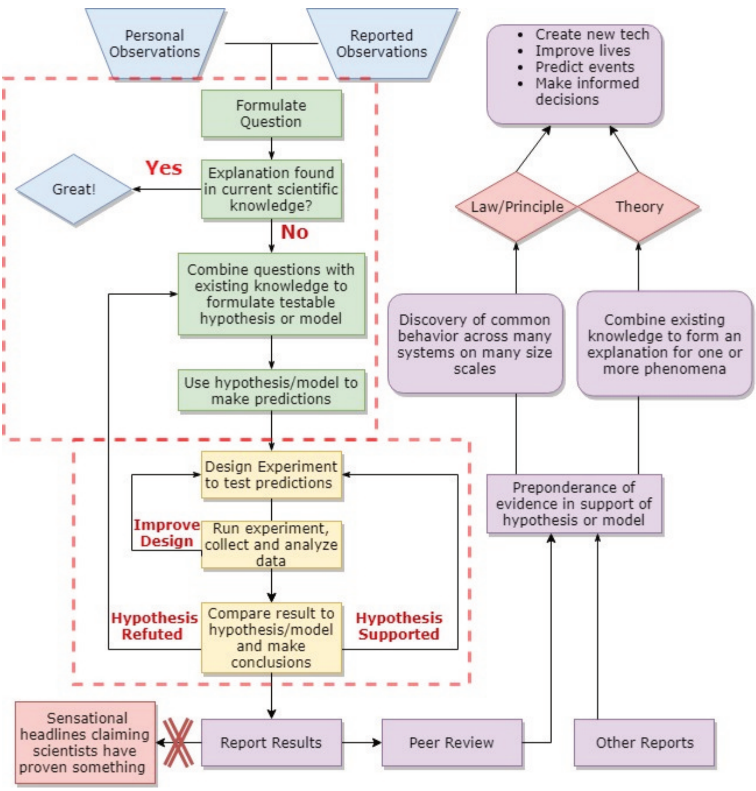
48. The Scientific Process

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:

A YouTube element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bpsupmat/?p=53

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.



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

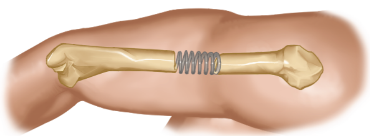
When a preponderance of evidence supports a particular *explanation* for observed occurrences (phenomena), then the explanation becomes a theory. Laws, principles, and theories are what the general public and media often refer to as scientific facts, but we don't need to introduce another definition 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.

PART III

OREGON COMMUNITY COLLEGE ASSOCIATION 2018 MEETING

Creating an OER physics textbook from a student-centered reference frame

Thank you



Artist's conception of the elastic behavior body tissues. "Arm Coil" by Sasha Lynch.

- UCC Faculty
- UCC Librarians
- OpenOregon
- Offices of: A&S Dean, Grants, Finance
- Office of the Provost
- Steve Loosely, BOE Chair
- Office of the President
- Audience
- Many Others

49. Body Balance App

What is your role in education?

1. student
2. parent
3. faculty member
4. staff
5. administration
6. board member
7. community member

How much would you pay for this app?

a) I wouldn't bother installing the app.
b) I'd install it for free
c) 0.99 **USD**
d) 4.99 **USD**

50. OER Familiarity

How familiar are you with OER?

I have

a) just heard about OER
b) known about OER for a while
c) considered using OER in my course (faculty)
d) have used OER in my course (faculty and students)
e) have considered creating OER
f) have created OER

51. Original OER Motivation

- Reduce cost to students
  - Free webview and digital file exports.
  - Low-cost hard copies through independent printers.
  - 1778 students saved 328,968.02 USD so far.
  - 2,101,633.44 USD Projected Savings.
  - 4.21 USD saved per 1 USD spent in the first

year alone.

52. Observations on Student-Textbook Interactions

From buzzfeed via foodbeast

What percentage of students 200-level physics students used the textbook as their primary study resource?

a) > 75 %
b) 50-75 %
c) 25-50%
d) < 25%

How often did most 200-level physics students

open the textbook?

a) Less than once per week
b) 2-4 times per week
c) 5-7 times per week

53. Survey of 200-level Physics Students

Anonymous Survey

Overall Usage

- < 12% read end-to-end
- 25% Don't use at all!
- > 50% open the textbook less than once per week!

Specific Usage

- 23% use the textbook as primary resource for HW
- 17% use the textbook as primary exam study resource

Textbook Usefulness

- < 54% find the textbook interesting
- < 50% think it even matters what textbook is used

A Textbook Paradox?

- 74% think using the textbook more would be the best way to improve performance....

54. Observations on Traditional Textbook Design

Mass Marketing

V-22 Osprey by James Haseltine (US Air Force) – USAF, *Public Domain, via wikimedia commons*

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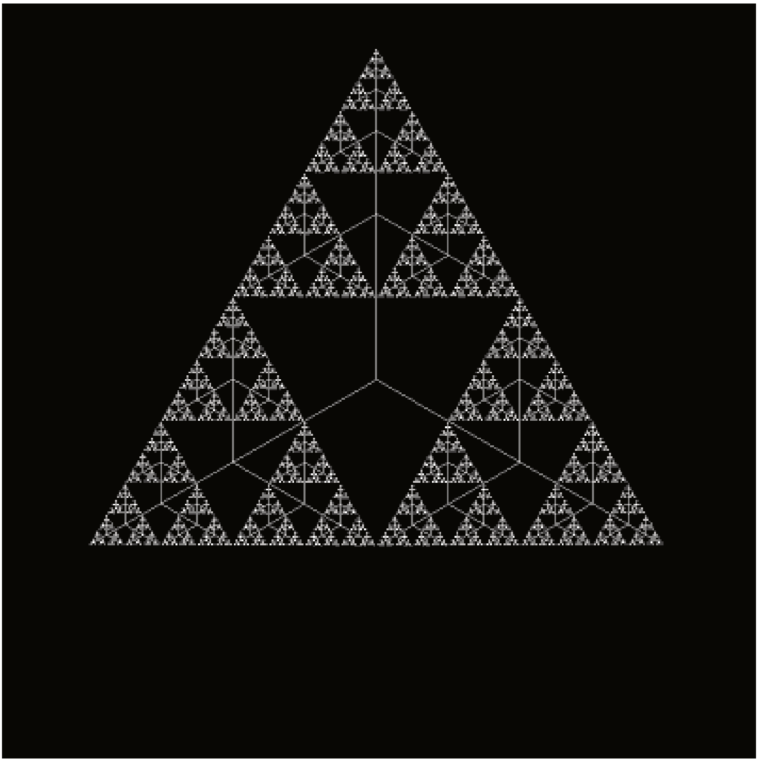
1. V-22 Osprey by James Haseltine (US Air Force) - USAF, Public Domain, https://commons.wikimedia.org/w/index.php?curid=57561

Perspective



Fractal Tree by Rafael Ruggiero via Wikimedia Commons

2

2. Fractal Tree by Rafael Ruggiero [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], from Wikimedia Commons

Wishful Thinking

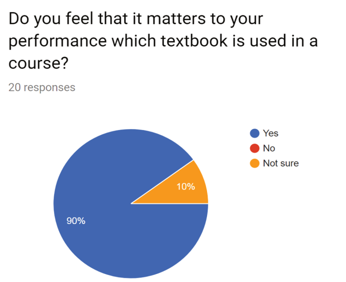
Boy studying by Lewis Hine [Public domain], via Wikimedia Commons

55. OER at the 100 Level

Student-Textbook Interaction

Fewer Resources

- Interest by experts
- Impact

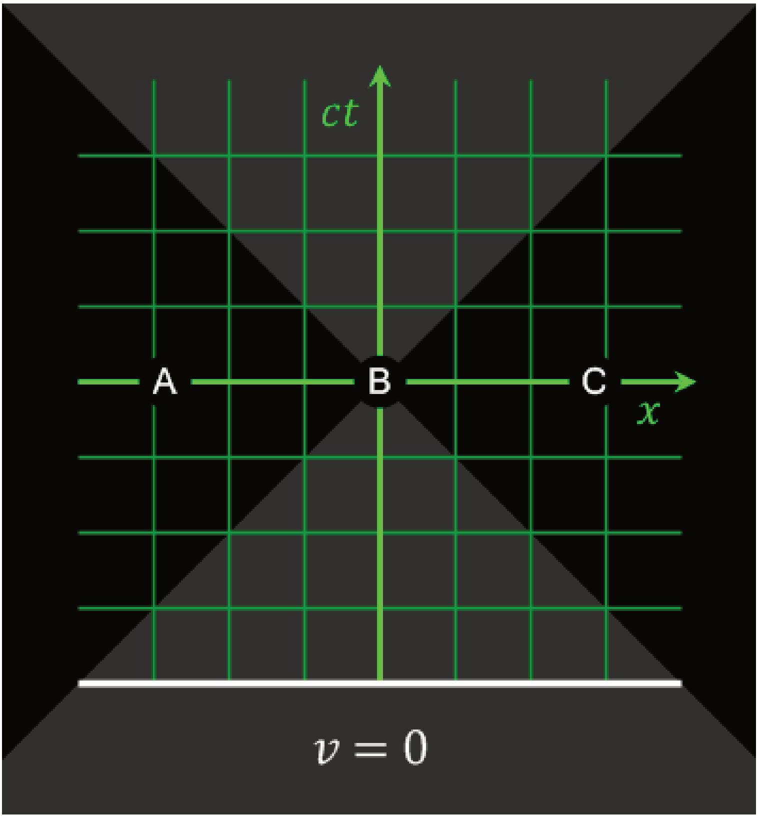


< 50% of 200-level students think it matters what textbook is used

Concepts before Context

Format Limited

56. Shifting Reference Frames



1

1. Relativity of Simultaneity Animation by Acdx [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], via Wikimedia Commons

- **Consider how *New* Student's Learn?**
  - **Context First**
  - **Content Second**
  - **Generalization Third**
  - **Early and Often Feedback**
- **Consider New Student Preparation**
  - **Set Expectations**
  - **Prepare for Barriers**
  - **Introduce Meta-cognition**
- **Just Ask: *How would you improve the textbook so that it would be more useful to***

you?

- **Index/Glossary**
- **More Examples and Reinforcement Exercises**
- **Other**

57. Crowd-Source Content


[1]

Engage Students

- Edits and Feedback
- Solutions and Data
- Images

Engage the Community

- Edits and Feedback

1. "bigdata_0" by Open Data Project, NASA is in the Public Domain

- Images
- Artwork

Engage Colleagues

- OCCA, OE Summit, IJOER
- bodyphysicstext@gmail.com

58. Initial Response

Community Response

- Mainstream Article
- UCC Marketing
- News-Review
- HECC
- KPIC Interview
- Featured in IJOER

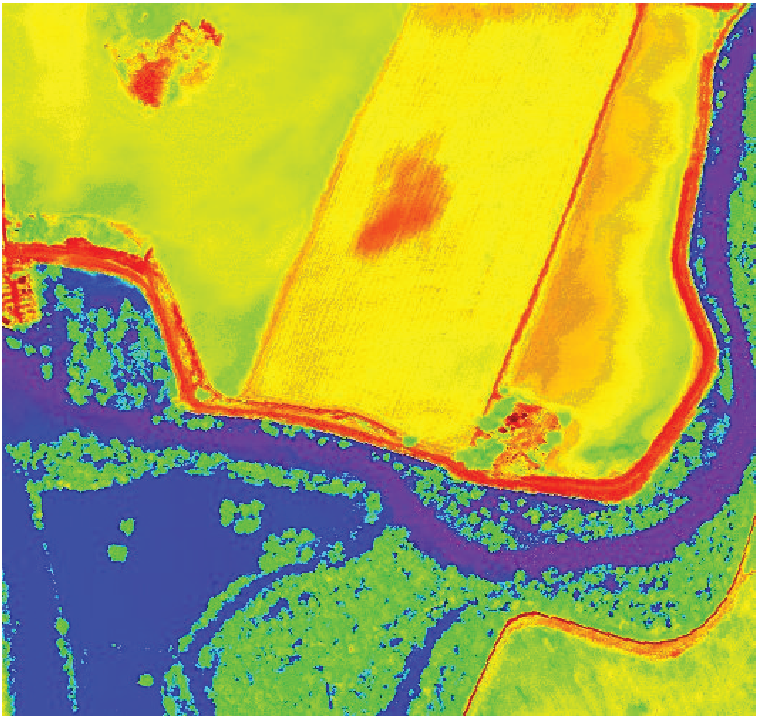
Student-Textbook Interaction

GS 104	Response	200-level General Physics
90%	Found the book interesting	54%
>50%	Textbook as primary resource	< 25%
75%	Opened more than once per week	< 50%
40%	Read chapters in full	12%
5%	Don’t really use the book	25%

How do you feel about OER?

a) skeptical
b) excited
c) mildly interested
d) waste of time
e) worthy of resource allocation

59. What Else?



Pseudo-color thermal image of the " San Joaquin River" by Airborne Science Program, NASA

- Open Education
    - DIY Monitoring and Sensors Workshop
- Collaboration Ideas
    - Progressive Practice for Tactile Technical Skills
        - Nursing
        - Science
        - Athletics

    - Drone based water quality sensing
        - CS
        - Engineering
        - NR
- Grants
    - Open Oregon
    - NSF S-STEM
    - Wishing Well
        - Fire Science
        - Physical/Biological Sciences
        - Engineering
        - STEAM Hub and other Outreach
- Research Ideas
    - Thermal properties of small streams from disparity in thermal and chemical breakthrough curves
    - Lagrangian frame tracking of downstream response to thermal perturbation
    - Effect of sensor size on Lagrangian frame data acquisition

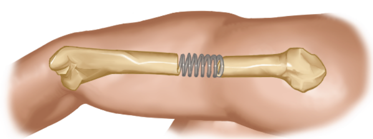
PART IV

CASCADIA OER SUMMIT 2019

Student Centered Design Components in Body Physics: Motion to Metabolism

Thank you

- Audience
- BCcampus/SFU
- OpenOregon
- Faculty & Librarians @ UCC and elsewhere
- Many Others



Artist's conception of the elastic behavior of body tissues. "Arm Coil" by Sasha Lynch.

60. Calibration Questions

Follow along: https://openoregon.pressbooks.pub/bodyphysics/
Live Polling: http://etc.ch/cgAD

How familiar are you with OER?

I have

a) just heard about OER
b) known about OER for a while
c) considered using OER in my course (faculty)
d) have used OER in my course (faculty and students)

e) have considered creating OER
f) have created OER

Results

How familiar are you with the PressBooks Platform?

I have

a) Never touched Pressbooks
b) Adpoted a Pressbook or Used the online viewer
c) Developed content with Pressbooks

Results

What are you most interested in hearing about?

a) Pressbooks features used in Body Physics
b) Observations and data on student-textbook interaction
c) Pedagogical thoughts behind Body Physics design
d) Overall process of creating an OER textbook

Results

61. Observations on Student-Textbook Interaction

From buzzfeed via foodbeast

What percentage of 200-level physics students used the textbook as their primary study resource?

a) > 75 %
b) 50-75 %
c) 25-50%
d) < 25%

Results

How often did most 200-level physics students open the textbook?

a) Less than once per week
b) 2-4 times per week
c) 5-7 times per week

Results

62. Survey of 200-level Physics Students

Anonymous Survey

Overall Usage

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63. Observations on Traditional Textbook Design

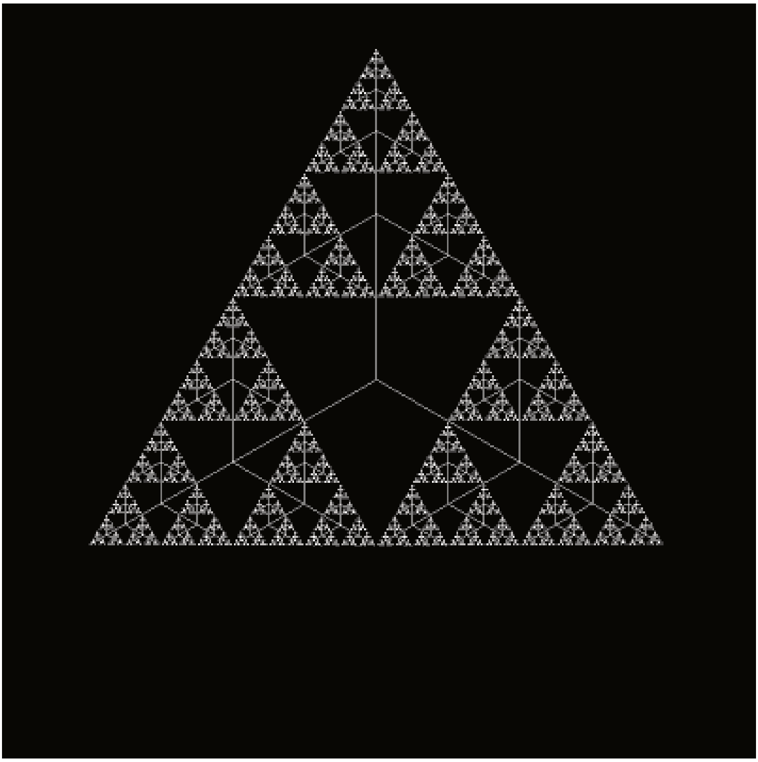
Mass Marketing

V-22 Osprey by James Haseltine (US Air Force) – USAF, *Public Domain, via wikimedia commons*

1

1. V-22 Osprey by James Haseltine (US Air Force) - USAF, Public Domain, https://commons.wikimedia.org/w/index.php?curid=57561

Perspective



Fractal Tree by Rafael Ruggiero via Wikimedia Commons

[2]

2. Fractal Tree by Rafael Ruggiero [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], from Wikimedia Commons

Wishful Thinking

Boy studying by Lewis Hine [Public domain], via Wikimedia Commons

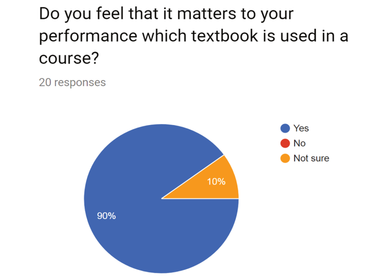
64. Audience Observations

Does the textbook you currently use fit into any of the previous categories?

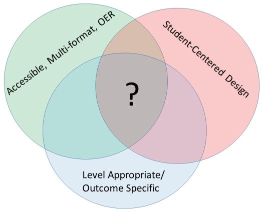
a) Mass Marketing
b) Perspective
c) Wishful Thinking
d) more than one of the above

Results

65. Physics OER at the 100-Level



< 50% of 200-level students think it matters what textbook is used



Challenge Accepted.

66. Backward Design

Backward Design

Course Outcomes

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.

Unit Learner Outcomes

Learner Outcomes

1. Identify tension, gravity, normal, and friction forces.[2]
2. Identify classes of levers and explain advantages and disadvantages of each in terms of mechanical advantage and range of motion.[2]
3. Apply lever and equilibrium concepts to solve for forces and find mechanical advantage in scenarios involving levers. [3]
4. Apply normal force and friction coefficient concepts to calculate static and kinetic frictional forces.[3]

Practice and Assessment Exercises

Outcome 1

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

- A car hanging from a crane (there are two forces).
- A car skidding to a stop (there are three forces).
- 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).

2) A person stands on a scale. What type of force is pulling them down? What type of force is provided by the scale to hold them up?

Outcome 2

4) Consider the following items:

- Pliers
- Tweezers
- Shovel

(a) For each case, draw a stick figure of the tool and label the fulcrum, effort, load, effort arm, and load arm.
(b) State the class of lever for each item above.

(c) For each item above, state whether the tool is providing mechanical advantage or increasing range of motion.

Outcome 3

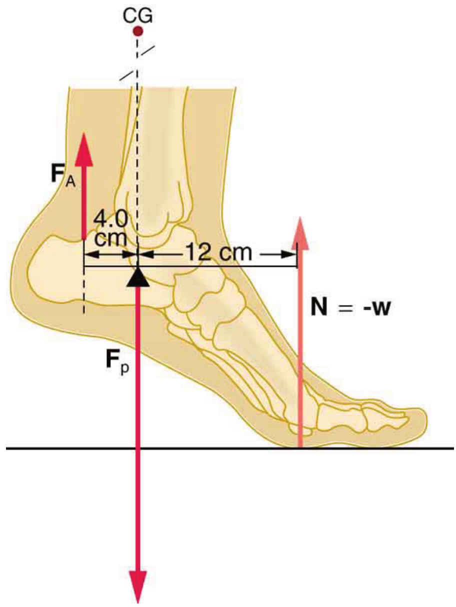
5) When a person raises their heels off the ground, the foot acts like a lever.

(a) Typically we consider the foot as a second class lever, but if we treat the ankle bone as the fulcrum, the tension in the calf muscle as the effort, and the normal force from the floor as the resistance, what class of lever is this system?

(b) Calculate the tension applied by the calf muscles (F_A) to lift a person with weight of 637 **N**.

(c) Calculate the force in the ankle joint between the foot and the lower leg bones (F_P). [*Hint: Both the normal force from the floor and the calf tension point upward. In order for the foot to be in static equilibrium, the force of the lower leg pushing down on the foot must cancel out both of those upward forces.*]

(d) Convert your final answers to pounds.



The foot acting as a lever arm. Image Credit: OpenStax College Physics

1

6) The head and neck are also a lever system.

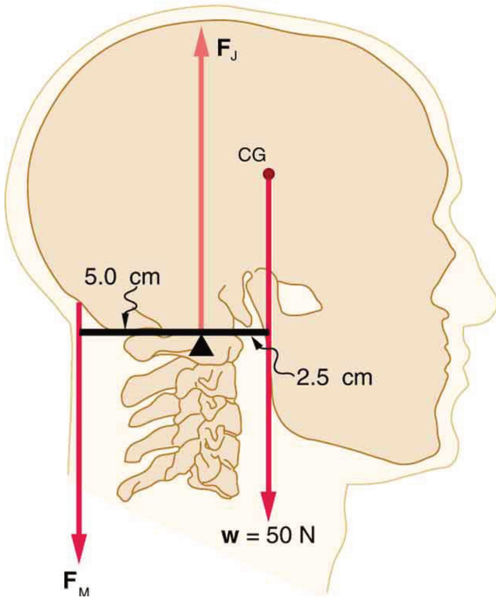
(a) State the class of this lever system.

(b) Calculate the force of tension in the neck muscles (F_M) to hold the head in the position shown in the diagram.

(c) Calculate the force on the head-neck joint (F_J).

(d) Convert your final answers to pounds.

1. OpenStax, College Physics. OpenStax CNX. Aug 3, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@11.42



The head and neck acting as a lever system.Image Credit: OpenStax College Physics

2

Outcome 4

7) Find a value for the kinetic coefficient of friction between ends of a bone in a synovial joint lubricated by synovial fluid. State your source.

2. OpenStax, College Physics. OpenStax CNX. Aug 3, 2018 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@11.42

8) If the normal force between bones in the knee is 160 **lbs**, what is the kinetic frictional force between the surfaces of the knee bones?

9) A car with 10,000 **N** weight is sitting on concrete with the parking brake on,

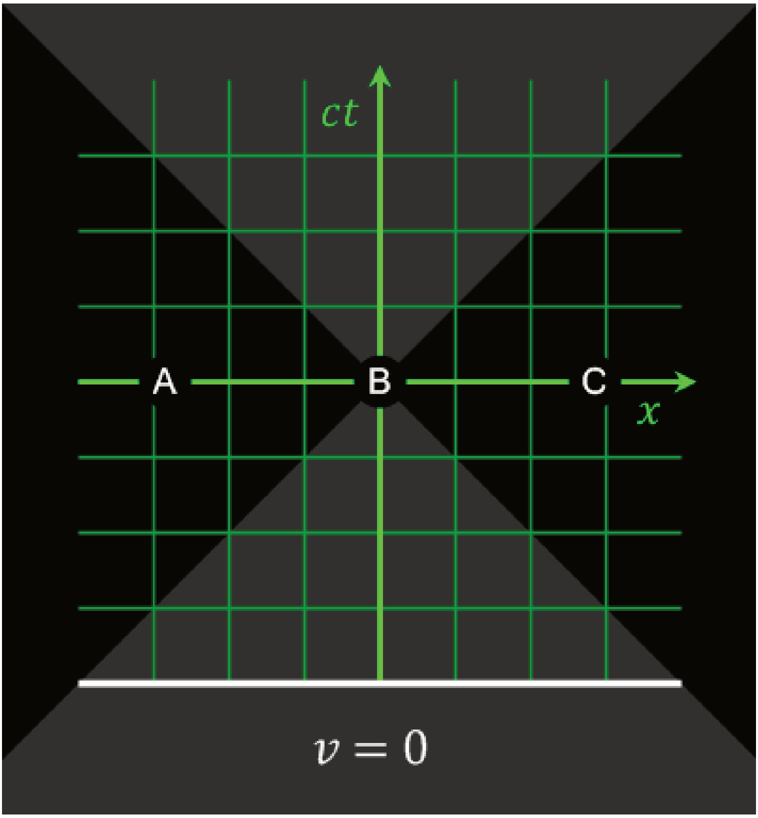
a) What is the normal force on the car from the concrete? [Hint: Is the car in static equilibrium?]

b) What is the maximum horizontal force that can be applied before the car begins to skid? List your sources for the friction coefficient.

c) After the car begins to skid, how much force is required to keep it moving?

d) If you apply only 120 **N** of horizontal force to the stationary car, what is the static frictional force at that time?

67. Shifting Reference Frames



1

1. Relativity of Simultaneity Animation by Acdx [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], via Wikimedia Commons

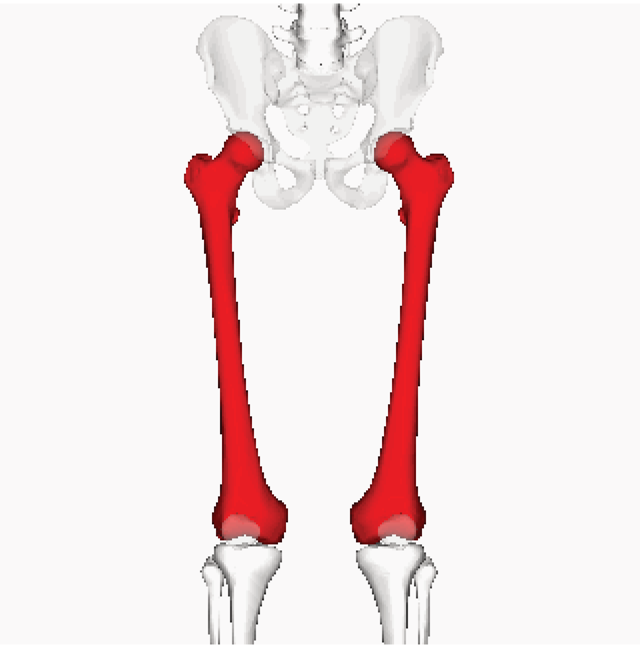
- ## Consider how *New* Students Learn
  - Context First
  - Content Second
  - Generalization Third
  - Early and Often Feedback (Flipped)
- ## Consider Student Preparation
  - Prepare for Barriers
  - Set Expectations
  - Introduce Meta-cognition
- ## Just Ask: *How would you improve the textbook so that it would be more useful to you?*
  - Glossary
  - More Examples and Reinforcement Exercises
  - Other

68. Additional Features Improving and Leveraging Digital Literacy

Videos

A YouTube element has been excluded from this version of the text. You can view it online here: https://openoregon.pressbooks.pub/bpsupmat/?p=435

GIFs



The Human Femur. Image Credit: Anatomography via Wikimedia Commons

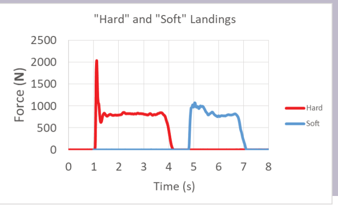
Personalized Data

Everyday Examples: Landing after a Jump

You naturally tend to bend your knees when landing after a jump, rather than keep your knees locked and your legs rigid. The reason is that rigid legs bring you to an abrupt stop, but bending your knees allows you to spread the landing out over a longer time, which we now know reduces the average force.

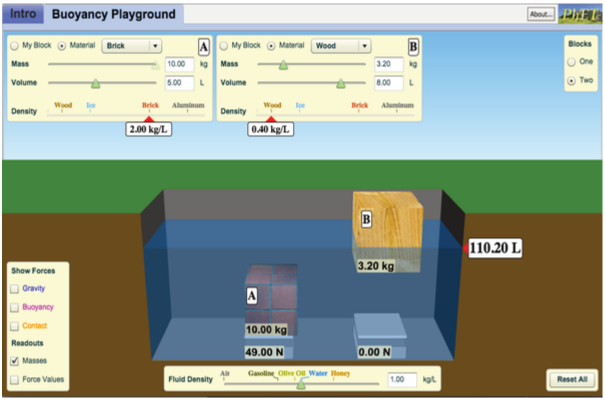
The force vs. time graphs show the normal force applied to a person when landing on one foot after stepping off from a 0.1 **m** height as seen in the previous GIF. The graph on the left was the more rigid leg landing (it didn't feel good) and the graph on the right was a bent-knee landing.

Notice that the stiff-legged “hard” landing nearly doubled the peak force applied to the body.



Force vs. time data for a stiff-legged landing (red) and crouching landing (blue).

Interactive Simulations

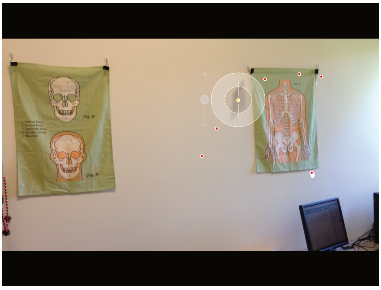


Phet Physics Buoyancy Simulation

Multimedia/Digital Data Acquisition Activities

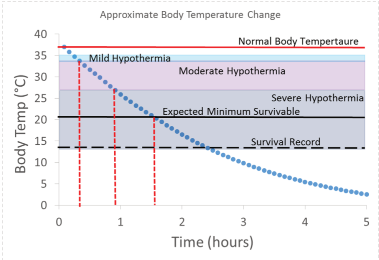
Simulation Building Activities

https://gfycat.com/HollowVengefulFlamingo



Video tracking a projectile

Numerical Modeling Activities



Numerical simulation of body temperature vs. time during a cold weather survival experience

69. Initial Response

Student-Textbook Interaction

GS 104	Question	200-level General Physics
90%	Found the book interesting	54%
>50%	Textbook as primary resource	< 25%
75%	Opened more than once per week	< 50%
40%	Read chapters in full	12%
5%	Don't really use the book	25%

Community Response

- Mainstream Article
- UCC Marketing
- News-Review
- HECC
- KPIC Interview
- Featured in IJOER

70. Crowdsource!

1

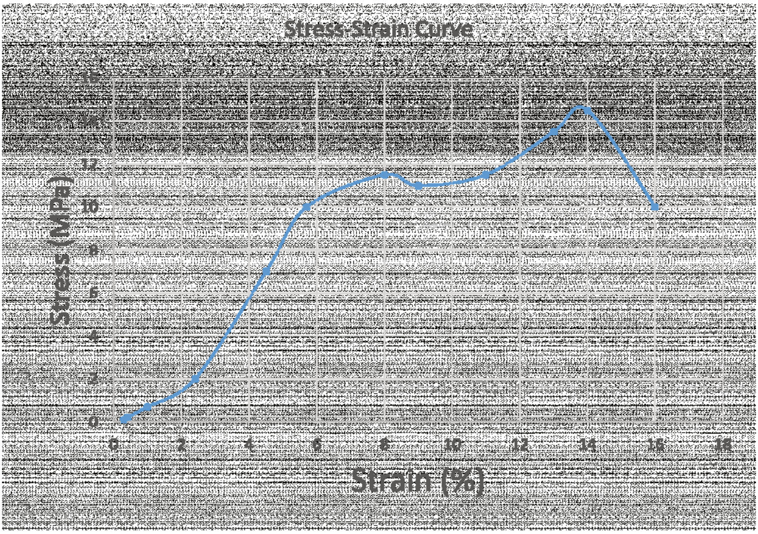
1. "bigdata_0" by Open Data Project, NASA is in the Public Domain

Engage Students

250+ Edits

Survey Data and Feedback

Solutions and Data



Data adapted from rubber band stress-strain data originally acquired by Umpqua Community College Students: Brittany Watts, Ashlie DeHart, Hanna Wicks and Juan Martinez.

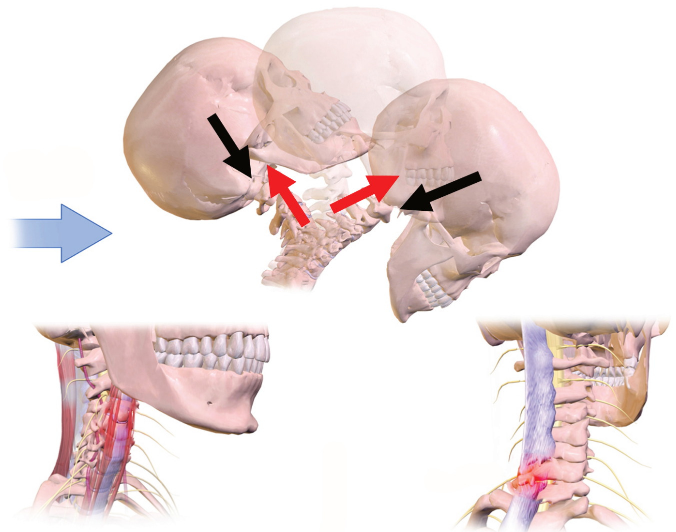
Images

Photograph of a 1 mm x 3 mm rubber band during stress testing. The band runs through the slots in the gray weights and the hook attached to the bottom of the band is just visible through the slot in the lowest group of smaller (0.98 **N***) weights. The 119* **N** *of force is applying* 1.3×10^{13} ***Pa*** *of stress, causing a strain of 660* **%**. *Photo credit: Umpqua Community College student Samual Marsters.*

Engage the Community

Edits and Feedback

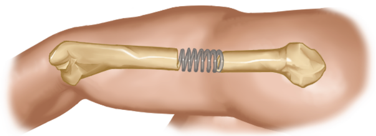
Diagrams



Top: Forces on the head from the neck (black) and on the neck from the head (red) during rapid forward-back motion of the head. Bottom: Sites of whiplash injury. Image Credit: This image is a derivative of Whiplash Injury by BruceBlaus, via Wikimedia Commons

Artwork

Engage Colleagues



Artist's conception of the elastic behavior body tissues. "Arm Coil" by Sasha Lynch.

OCCA, OER Symposium, OE Summit, IJOER

bodyphysicstext@gmail.com

71. Original OER Motivation

GS 104 students at Umpqua Community College

Accessibility

- Free webview and digital file exports.
- Screen Reader Ready
- Low-cost hard copies through independent printers.

GS 104 students at Umpqua Community College

PART V

PHYSICS FROM THE STUDENT PERSPECTIVE

Project Description

Outline

In groups of two, you will create one chapter of an open textbook for 100-level non-science majors.

You will have the choice of whether or not your final product is shared openly. This choice will not affect your grade.

Your chapter will introduce a topic we have covered this term in the context of a real-life example. You should check out what an example of such a chapter would look like.

Your work should be in your own words and reflect the way you personally understand the material being covered.

Details

You will need to include at least one ancillary feature, such as a link to a relevant video, simulation. These must be linked, or preferably embedded in the chapter.

You must include at least one image that helps a reader to visualize the content you are writing about.

You must use at least one diagram to help explain your topic. The diagram must include a caption and alternative text.

You will need to have at least one worked out Example problem.

You will need to have at least one Reinforcement exercise or question for students to reading the book to answer for themselves. You will need to provide the answer/solution to this problem to your instructor, but it will not appear in your chapter.

Any problems, images, diagrams you use must be either your own or found in the public domain or open source, meaning they can be used without permission under a creative commons copyright licence. Wikimedia commons is good place to start. Often information on government websites sites under public domain. If you are unsure about a copyright, check with your instructor or a librarian.

References

All sources of information including must be cited using footnotes, including ideas, text, images, diagrams, example problems, solutions, etc. Follow these guidelines to avoid plagarism.

Use the open attribution builder to maintain consistency in your citations.

Accessibility

Your chapter should follow a standard heading structure. All images and diagrams should contain alternative text. If colors are important to understanding an image or diagram, those colors should be black, blue, pink.

Platform

We will use the Pressbooks platform to create our chapters. The Pressbooks editor looks like a typical word processor such as Microsoft Word or google docs and makes embedding videos, images, and citations really easy with a couple of mouse clicks.

Additionally, pressbooks makes adding alternative text and captions to images easy.

Equations are more difficult to render in Pressbooks. If you are interested in learning Latex typesetting code I'll help with that. Otherwise use an online program which creates an image of your equation that you can embed in Pressbooks. The equations can be converted later (by me).

You should get an invite to our book soon. In the meantime you can work in another word processor and easily import to Pressbooks later.

Timeline

Outline (Week 6)

Your group will submit a basic outline/plan of your chapter before **the end of week 6** of the term.

Revision (Week 8)

Your group will go through at least one revision process which involves meeting with your instructor to discuss a complete rough draft of your chapter. Working with your instructor, you will apply the rubric found below to your draft in order to identify strengths and weaknesses in your draft and prioritize improvement efforts. This draft will not be graded, but will fulfill the *revision* requirement in the rubric. The revision meeting must happen before **the end of week 8.**

Peer Feedback (Week 9)

Your group will work with at least one other group to exchange peer feedback. You will take notes on the feedback you receive and add brief comments about what changes you make in response to that feedback. These will be submitted to your instructor to fulfill the *Presented to Peers* requirement in the rubric. This must happen before **the end of week 9.**

Final Submission (Week 11)

Your group will submit a final completed chapter in electronic format before the **start of week 11.**

Project Grading

Your final will be graded according to the following rubric, which the class developed together.

Project Rubric

	Ready for Inclusion (4pts)	Needs Minor Improvement (3pts)	Needs Major Improvement (2pts)	Lacking Basic Structure (1pt)
Process	Researched Topic (≥ 4 content refs) Submitted outline Created page Presented to peers (submit notes) Revision (submit notes)	Researched Topic (≥ 2 content refs) Submitted outline Created page Presented to peers (submit notes) Revision (no notes)	Researched Topic (≥ 1 content refs) Submitted outline Created page Did not Presented to peers (no notes) No Revision (no notes)	No Research refs No outline Created page Did not Presented to peers (no notes) No Revision (no notes)
Accuracy	No textual errors No equation errors No content errors	≤ 7 textual and equation errors No content errors	> 7 textual and equation errors ≤ 2 content errors	> 2 content errors
Effort	Relevant Image Neat, Helpful Diagram Relevant Videos Complete, correctly formatted references	Relevant Image Helpful Diagram Relevant Videos Complete References	Irrelevant Image Not Helpful Diagram Irrelevant Video Missing References	No Image No Diagram No Video No References
Example	Relevant 100-level appropriate Broken into multiple steps Correct Solution	Relevant Broken into multiple steps Correct Solution	Not Relevant Not Relevant broken into multiple steps Correct Solution	Incorrect Solution

Exercise	Relevant 100-level appropriate Correct Solution	Relevant Correct Solution	Not Relevant Correct Solution	Incorrect Solution

Glossary

1st Law of Thermodynamics

Any change in the internal energy of a system must in the process of exchanging heat, doing work, or both.

3rd class lever

a lever with the effort between the load and the fulcrum.

Achilles tendon

a tough band of fibrous tissue that connects the calf muscles to the heel bone

Archimedes' Principle

The upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid being displaced by the body

BMI

Body Mass Index (BMI) is a person's weight in kilograms divided by the square of height in meters. BMI can be used to screen for weight categories that may lead to health problems but it is not diagnostic of the body fatness or health of an individual

Barriers

Objects, events, or conditions that hinder access.

Bloom's Taxonomy

Blooms Taxonomy

Bloom's Taxonomy

A framework for categorizing educational goals.

Carnot efficiency

the maximum theoretical efficiency that a heat engine could achieve when operating between two set temperatures, as permitted by the Second Law of Thermodynamics

Cognition

The mental action or process of acquiring knowledge and understanding through thought, experience, and the senses

Computer modeling

using a computer program that is designed to simulate what might or what did happen in a situation

Empirical models

mathematical explanation of the relation between measured values that is used for making predictions

Energy

A quantity representing the capacity of an object or system to do work.

Energy pathway

the process of transferring chemical potential energy stored in food to useful work and thermal energy

Entropy

A measure of energy dispersion in a system.

Feedback

1) information about reactions to a product, a person's performance of a task, etc. which is used as a basis for improvement.
2) the modification or control of a process or system by its results or effects, e.g., in a biochemical pathway or behavioral response

Glossary

The glossary feature includes rollover definition capability.

Green House Gas Effect

Elevation of Earth's temperature relative to the atmosphere-free condition caused differential absorption of UV, visible, and IR light by specific gases and particles present in the atmosphere.

Heat

An amount of thermal energy transferred due to a difference in temperature.

Heat death

the degradation of energy quality associated with a spontaneous processes.

Hyperthermia

The condition of having a body temperature well above the normal range.

Isolated system

a system for which neither thermal energy or particles are allowed to leave or enter.

Latent heat

the thermal energy required to change the phase of a substance (or released by the substance when it changes phase)

Learning management system

a software application for the administration, documentation, tracking, reporting, and delivery of educational courses, training programs, or learning and development programs

Melting

changing phase from solid to liquid.

Metacognition

awareness and understanding of one's own thought processes

Multitasking

Splitting attention between more than one task at a time.

Natural convection

Transfer of heat due to fluid movement caused by thermal expansion of the fluid

Newton

the SI unit of force. It is equal to the force that would give a mass of one kilogram an acceleration of one meter per second per second

Newton's Law of Cooling

Observation that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the environmental temperature

Newtons

Physical models

mechanistic explanation of how a physical system works

Relative humidity

a measure of how many water molecules are in the vapor phase relative to the maximum number that could possibly be in the vapor phase at at a given temperature. A relative humidity of 100% means that no more water molecules can be added to the vapor phase.

Spontaneous process

a process which occurs naturally on its own, without the need for work to be done in forcing it to happen.

Stephan-Boltzmann Law

The total radiant heat energy emitted from a surface is proportional to the fourth power of its absolute temperature.

Study strategy

a thoughtful and specific process for self-directed learning.

Systematic errors

an error having a nonzero mean (average), so that its effect is not reduced when many observations are averaged. Usually occurring because
there is something wrong with the instrument or how it is used.

Thermal power

rate at which chemical potential energy is converted to thermal energy by the body, batteries, or heat engines. Also, rate at which thermal energy is converted to electrical energy by a thermal power plant.

Universal Law of Gravitation

every particle attracts every other particle in the universe with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers

Work

A quantity representing the effect of applying a force to an object or system while it moves some distance.

absolute zero

A lower limit of temperature corresponding to the minimum possible average kinetic energy of atoms and molecules.

acceleration

the change in velocity per unit time, the slope of a velocity vs. time graph

acceleration due to gravity

the rate at which an object changes velocity when gravity is the only force acting on the object

accurate

refers to the closeness of a measured value to a standard or known value

air resistance

a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid

analyze

examine methodically and in detail the constitution or structure of information for purposes of explanation and interpretation

apparent weigh

apparent weight

the reading on a scale that is used to measure the weight of an object that is submerged in a fluid

approximation

a rough value obtained without making a measurement by using prior knowledge and assumptions.

assumption

ignoring some compilation of the in order to simplify the analysis or proceed even though information is lacking

at rest

not moving

average speed

average rate at which distance was traversed, equal to total distance traveled within a time interval, divided by the time interval

average velocity

the average of all instantaneous velocities that occurred within a certain time interval, equal to the displacement divided by the time interval

bedrock

hard rock exposed or buried at the earth's surface

biased

prejudice in favor of or against one thing, person, or group compared with another, usually in a way considered to be unfair or inaccurate.

bipedal

(of an animal) using only two legs for walking

buoyant force

the upward force exerted by any fluid upon a body placed in it

buoyant force

cantilevered

any rigid structure projecting from a support, especially one in which the projection is great in relation to the depth of the structure

center of gravity

a point at which the force of gravity on body or system (weight) may be considered to act. In uniform gravity it is the same as the center of mass.

center of mass

a point representing the mean (average) position of the matter in a body or system

chain-link method

a specific method for unit conversion that is designed to aid in reducing mistakes.

coefficient of friction

compression

reduction in size caused by application of compressive forces (opposing forces applied inward to the object).

conclusion

a judgment or decision reached by reasoning and logic based on results provided by analysis of data

condensation

Process of vapor changing phase into a liquid.

constant

not changing, having the same value within a specified interval of time, space, or other physical variable

convection cell

cyclic fluid flow caused by natural convection

conversion factor

a number that relates two different units of measure for the same quantity and allows conversion between the two units

crust

the relatively thin layer of rock that makes up the outermost solid shell of our planet

data

collection of values measured during an experiment

density

relation between the amount of a material and the space it takes up, calculated as mass divided by volume.

derivation

a sequence of steps, logical, mathematical, or computational, combining one or more results to obtain another result

dew

water that condenses on cool surfaces at night, when decreasing temperature forces humidity to 100% or higher

displaced

pushed out of original position, typically in reference to fluid pushed out of the way by an object placed in the fluid, or an object being displaced from its equilibrium position

displacement

change in position, typically in reference to a change away from an equilibrium position or a change occurring over a specified time interval

displacement method

method for determining the volume of an object by measuring how much water it displaces

effort

referring to a lever system, the force applied in order to hold or lift the load

elastic region

the range of values for stress and strain values over which a material returns to its original shape after deformation

equilibrium

a state of having no unbalanced forces or torques

final velocity

the value of velocity at the end of the time interval over which motion is being analyzed

force

any interaction that causes objects with mass to change speed and/or direction of motion, except when balanced by other forces. We experience forces as pushes and pulls.

force of gravity

attraction between two objects due to their mass as described by Newton's Universal Law of Gravitation

forced convection

transfer of heat due to the movement of fluid molecules driven by external factors other than thermal expansion.

free body diagram

a graphical illustration used to visualize the forces applied to an object

friction

a force that acts on surfaces in opposition to sliding motion between the surfaces

fulcrum

the point on which a lever rests or is supported and on which it pivots

gravity passes

heat capacity

The amount of energy required to raise the temperature of an object by one temperature unit.

histogram

A graph of relating how often a value falls within a certain range.

hydrostatic weighing

a technique for measuring the mass per unit volume of a living person's body. It is a direct application of Archimedes' principle, that an object displaces its own volume of water

hypothermia

The condition of having a body temperature well below the normal range.

hypothesis

a proposed explanation made on the basis evidence that can be supported or refuted by the result of experimentation

inelastic collision

a collision for which kinetic energy is not conserved

irreversible

a process that is not a reversible process in which the system and environment can be restored to exactly the same initial states that they were in before the process

kelvin

SI unit of temperature

kinetic friction

a force that resists the sliding motion between two surfaces

latent heat of fusion

the thermal energy required to melt a unit mass of a substance

latent heat of vaporization

Thermal energy input required to change a unit mass of liquid into vapor.

law

a statement, usually in the form of a mathematical equation, that summarizes, but not explains, the results of repeated experiments or observations that describe some aspect of the natural, usually within a certain range of application.

lever

a rigid structure rotating on a pivot and acting on a load, used multiply the effect of an applied effort (force) or enhance the range of motion

lever classes

There are three types or classes of levers, according to where the load and effort are located with respect to the fulcrum

linear thermal expansion coefficient

Material property that relates the fractional change in length experienced by an object due to a unit change in temperature.

magnitude

the size or extent of a vector quantity, regardless of direction

mass

a measurement of the amount of matter in an object made by determining its resistance to changes in motion (inertial mass) or the force of gravity applied to it by another known mass from a known distance (gravitational mass). The gravitational mass and an inertial mass appear equal.

measurement error

Measurement Error (also called Observational Error) is the difference between a measured quantity and its true value. It includes random error (naturally occurring errors that are to be expected with any experiment) and systematic error (caused by a mis-calibrated instrument that affects all measurements)

measurement units

a unit of measurement is a definite magnitude of a quantity, defined and adopted by convention or by law, that is used as a standard for measurement of the same kind of quantity. Any other quantity of that kind can be expressed as a multiple of the unit of measurement.

metastable equilibrium

a state in which a slight disturbance results in a restoring force that maintains stability, but a sufficiently large disturbance moves the system into an unstable region (or different metastable region)

method of significant figures

using the number of digits provided in a measurement value to indicate the measurement uncertainty

metric prefix

a unit prefix that precedes a basic unit of measure to indicate a multiple or fraction of the unit

model

a representation of something that is often too difficult (or impossible) to observe or display directly

nervous system

the network of nerve cells and fibers which transmits nerve impulses between parts of the body

net force

the total amount of remaining unbalanced force on an object

net torque

remaining unbalanced torque on an object

non-conservative forces

forces that do non-conservative work, which is work that does not transfer energy only among kinetic and potential forms (mechanical energy)

normal force

the outward force supplied by an object in response to being compressed from opposite directions, typically in reference to solid objects.

null hypothesis

default position that there is no relation between two measured quantities

order of magnitude

designating which power of 10 (e.g. 1,10,100,100)

order of magnitude estimation

the process of approximating a value to obtain a result you expect to at least be within one order of magnitude of the correct answer.

origin

location where the position is zero

perpendicular

at an angle of 90° to a given line, plane, or surface

pivot

the central point, pin, or shaft on which a mechanism turns or oscillates

pounds

a unit of force equal to 4.44822 Newtons, or the the weight of a 0.4536 kg mass on Earth's surface

precision

refers to the closeness of two or more measurements to each other

preponderance

the quality or fact of being greater in number, quantity, or importance

principle

principles summarize rules created and followed by scientists when formulating hypotheses, designing experiments, analyzing results.

qualitative

describing what happens, but not how much happens

quantitative

describing what and how much happens

radians

radians (rads)

a unit of angle, equal to an angle at the center of a circle that produces an arc length equal to the radius

random error

random errors are fluctuations (in both directions) in the measured data due to the precision limitations of the measurement device. Random errors usually result from the experimenter's inability to take the same measurement in exactly the same way to get exact the same number

reactive force

a type of force supplied by an object in response to application of a different force on the object. Friction is a reactive force

resistance

the force working against the rotation of a lever that would be caused by the effort

restoring force

a force that tends to move a system back toward the equilibrium position

results

information acquired by analyzing data

rotational equilibrium

a state of having not net torque and no change in rotational motion

rupture

the sudden and complete failure of a material under stress

scientific method

a method of procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses

scientific notation

a way of writing very large or very small numbers. A number is written in scientific notation when a number between 1 and 10 is multiplied by a power of 10.

significant figures

each of the digits of a number that are used to express it to the required degree of accuracy, starting from the first nonzero digit

skinfold method

method for measuring body fat percentage using specially designed calipers to measure the thickness of skinfolds that are pinched from several specific locations on the body as inputs to empirical equations

specific gravity

the ratio of the density of a substance to the density of a standard, usually water for a liquid or solid, and air for a gas

specific heat

A material property that determines the amount of energy required to raise the temperature one mass unit of the material by one temperature unit.

stability

a measure of the displacement from equilibrium an object can experience and still move back toward equilibrium

stable equilibrium

a state in which a body tends to return to its original position after being disturbed

standard scientific (SI) units

a system of physical units (SI units) based on the meter, kilogram, second, ampere, kelvin, candela, and mole

static equilibrium

the state being in equilibrium (no unbalanced forces or torques) and also having no motion

static friction

a force that resists the tenancy of surfaces to slide across one another due to a force(s) being applied to one or both of the surfaces

strain

the measure of the relative deformation of the material

stress

a physical quantity that expresses the internal forces that neighboring particles of material exert on each other

support base

region defined by lines connecting points of contact with the supporting surface

tension

the force that is provided by an object in response to being pulled tight by forces acting from opposite ends, typically in reference to a rope, cable or wire

test conditions

an item or event of a component or system that could be verified by one or more test cases, e.g., a function, transaction, feature, quality, attribute, or structural element

theory

an explanation of an aspect of the natural world that can be repeatedly tested and verified in accordance with the scientific method using accepted standard protocols

thermal equilibrium

a two systems are in thermal equilibrium when they do not exchange heat, which means they must be at the same temperature

thermal expansion

The increase change in volume of an object resulting from a change in temperature.

thermal radiation

Electromagnetic radiation spontaneously emitted by all objects with temperature above absolute zero.

thermometer

a device that measures temperature

tipping point

the point at which an object is displaced from a region of stable equilibrium

torque

the result of a force applied to an object in such a way that the object would change its rotational speed, except when the torque is balanced by other torques

torques

translational motion

motion by which a body shifts from one point in space to another (up-down, back-forth, left-right)

uncertainty

Amount by which a measured, calculated, or approximated value could be different from the actual value

under water weight

apparent weight when submerged in water

uniformly

in a way that is the same in all cases, across a defined set of space and times

unit analysis

act of ensuring that the units resulting from a calculation match the type of quantity calculated.

unstable equilibrium

a state of equilibrium such that when the body is slightly displaced it departs further from the original position

vectors

a quantity having direction as well as magnitude

velocity

a quantity of speed with a defined direction, the change in speed per unit time, the slope of the position vs. time graph

volume

a quantity of space, such as the volume within a box or the volume taken up by an object.

weight

the force of gravity on on object, typically in reference to the force of gravity caused by Earth or another celestial body

wind chill effect

Increase in rate of heat loss from objects that are warmer than air caused by the flow of air across the object surface.

work-energy principle

the change in kinetic energy of an object or system is equal to the net work done on the object or system