Double Units in Physics: Can you walk faster than a plane flies?

Overview
Within this lesson, students will learn to perform double unit conversions. Students will also be introduced to the concepts of velocity and nano-scale by placing very slow and very fast objects on a number line. Throughout the activity, students will have the opportunity to interact and argue their stance on where the various objects should be placed on the number line (also referred to as the “velocity line” throughout this plan). Finally, students will learn to perform dimensional analysis on double-units and practice using conversion factors to convert the given velocity of each object to meters per second or kilometers per hour. Students will also have the opportunity to look at photos at the nanoscale. With each photo, they can determine the exact dimensions of the presented object utilizing the provided scale on the photo.

Key Search Words
9-12 Physics, dimensional analysis, kinematics, speed, velocity, motion, scale, conversion factors, number line, measurement, nanoscale, nanotechnology

Learning Objectives
- Students will be able to rank speeds with various units (cm/s, m/s, and km/h) on a line from slowest to fastest.
- Students will be able to create their own conversion factors using a ruler and a scale.
- Students will be able to compare and convert dimensions and speeds utilizing conversion factors with 80% correctness.

Curriculum Alignment
North Carolina Essential Standards
- Phy.1.1.1 Analyze motion numerically.
- Phy.1.1.2 Analyze motion in one dimension using speed.

NGSS Practices
- Using mathematics and computational thinking
- Engaging in arguments from evidence

Classroom time required
- One 90-minute class period
  - Two 50-minute lessons may be appropriate
  - Denoted lesson parts can be left out to use this lesson for one 50-minute period

Materials & Technology
Materials
- 15-20 feet of clothesline or string to be hung in a visible location in the classroom that will not block students’ view of the screen projection
- 3-5 clothespins per student
- Scissors
- Printed copies of the Speeding Objects - included in Appendices
- Printed/written copies of m/s scale and speeds - included in Appendices
- One notebook per student or other form of note-taking medium
- One writing utensil per student
- 5-10 rulers, or one per student
- *Optional:* classroom set of personal whiteboards

Technology
- Google Slides - PDF in Appendices
- One laptop for projecting slides
- Projector
- One scientific calculator per student

Safety
There are no safety concerns involved with this lesson.

Teacher Preparation for Activity

Teachers should print two copies of the attached worksheets–one to keep as a key and one to cut. Teachers should cut out the Speeding Objects and m/s scale and speeds and hang the clothesline prior to the start of the lesson.

Student Preparation for Activity

Before beginning the lesson, students should have an understanding of the units for speed. For example, if the unit is miles per hour, they should understand that this means the object travels *X* number of miles in one hour. Additionally, students should have already learned the metric prefixes and the metric prefix scale from nano- (10^{-9}) to giga- (10^{9}).

Procedure

- *Warm-Up*: Explain/remind students of metric prefixes from nano- to giga-
    - Ask students the name or power for each prefix to gauge understanding
    - Have students write a list of the prefixes on the board as you all review
    - Have all students copy this list into their notes
- Explain that the clothesline at the side/front/back of the room is going to be made into a number line
    - Pass out clothespins, cutouts of objects, and speeds to students
    - Each student should get at least one cutout to hang up at some point during the activity. It's okay if some students have multiple. Some objects/speeds may be excluded for the sake of students having equal amounts of items to hang, if that suits the class better.
- Tell students that their objective is to place all of these cutouts in the correct order, from slowest to fastest, beginning with the Speeding Object cutouts.
    - Allow students to hang their provided objects one-by-one in a specific place on the line
    - Ask students periodically to explain why they chose a given location for the object
    - Ask the rest of the class to agree/disagree with the placement of an object
        - *Suggestion:* Ask these questions when students are hanging the Earth's Orbit and Earth's Rotation cutouts – these speeds are surprisingly fast and many students may not expect where they fall on the line.
    - After all cutouts have been hung, ask if anyone has changes they think should be made to the current state of the velocity line. Whether these changes are made or simply vocalized is up to the students.
- Next, allow students to match their provided velocities (not the 10^{x} cutouts, yet) to the hanging objects by pinning them to the object on the line.
    - *Emphasize:* If the student thinks the objects are hanging in the wrong order, they may place the velocities out of order. We will find out the correct order after all the speeds have been placed on the line.
    - After all of the speeds have been placed, read the answer key aloud and make any necessary corrections to the velocity line. There may be mistakes in the order of placement or incorrect matches of objects with their speeds.
- Work through each speed and converting it to m/s using conversion factors
    - Perform 1-2 conversions on the board slowly, pointing out conversion factors, correct placement of numbers in the numerator and denominator, and how to check that all the units are canceled correctly.
    - Have students complete 1-2 conversions on their own and check their answers with you before moving on to convert the rest of the speeds.
    - Allow students to work for about 30 minutes, converting each of the object's speeds to meters per second.
        - Actively monitor students and answer questions as needed.
        - Suggestions for differentiation are mentioned in a later section.
- Pass out 10^{x} m/s cards and allow students to hang their 10^{x} m/s cards on the number line in the correct place based on their conversions of the already hanging speeds.
    - *Emphasize:* Spacing does not have to be perfect, but students should be able to explain whether a speed falls closer to one 10^{x} m/s card or another.
        - Example: 0.002 falls between 10^{-3} and 10^{-4}, but is much closer on a number line to 10^{-3}.
    - After each 10^{x} m/s card has been placed, ask students if there is any change they think should be made to the velocity line.
    - Finally, check the line with the key.
- Ask students if there were any surprises or takeaways from this activity.
    - Which object's speed was most surprising to you?
    - What's another object you would place on the line, and where do you think it would fall?
- Transition into talking about size
- Pull up slide deck - included in Appendices

- *OPTIONAL:* Begin by splitting students into groups of 2-3. Each group will need at least 2 rulers.
  - Explain the instructions (as demonstrated on Slide 2 - in Appendices) for measuring the particle in question and converting its dimensions into nanometers
    - Students should create their own conversion factor based on the scale in the image
    - *Suggestion:* Have students use two rulers to line up and move progressively over the image while measuring across the board, so they don't have to roughly estimate.
  - Allow groups to choose one of the images to measure (At least one group should measure each image, but depending on class size, multiple groups will be measuring the same image.)
  - Have groups take turns measuring their images in any manner that seems appropriate.
    - *Suggestion:* To prevent crowding and keep students moving, have groups measure their scale and record the length in their chosen units. Then, have them measure the dimensions of the object in those same chosen units. Finally, have them return to their seat to create their conversion factor and complete the conversion to nanometers.
    - *Suggestion:* This may be completed on paper or on personal whiteboards so that students can show their answers from their desks.
  - After each group has completed their measurement and conversion, compare their results with the following answer key for each image. Note that the answer key is approximate, and there is room for error based on rounding and precision.
    - Gold Particle diameter = 27.78 nm
    - Alien height = 2500 nm, alien head width = 1700 nm
    - E.coli (longest bacteria) height = 580.65 nm, length = 3935.48 nm
    - Ant head (lighter contrast portion) height = 400,000 nm, width = 580,000 nm
    - MRSA (singular bacteria) diameter = 750 nm
    - Pollen (singular) diameter = 95,238.10 nm
- *IF OMITTING OPTIONAL:* Ask students to locate the scale on each image and name the units provided.
- Point out visible textures and other unique features of the images.

- *Closing*: Ask students to answer one of the following questions, which will be projected on the slides.
  - Why is it important to know the scale of a given number value?
    - Potential response: 5 nm is very different from 5 ft or 5 miles and our conclusions will change based on the context
  - Why might it be useful to look at and talk about objects on the nano-level?
    - Potential response: Looking at and talking about objects at this level can allow science to progress at an even smaller physical level.
  - What are some different examples of applications of using technology to look at nanoscale objects?
    - Potential response: Looking at the COVID19 virus

Differentiation

- Adaptations for students with learning difficulties:
  - Provide printed copies of metric prefixes and common conversion factors
  - Pair correctly matching objects with their speeds before having students place them on the number line
  - Work through each of the conversions from given speed units to meters per second on the board instead of having students work individually
  - During image measuring activity, provide students with a conversion factor for each image, instead of having them create one, and assist them with converting those measurements to nanometers
  - Provide language supports for vocabulary and mathematical processes
  - Repeat instructions frequently and allow wait time when asking questions
  - Actively walk throughout the room
- Adaptations for students with gifts and talents:
  - Have students create 10^x cards, instead of passing them out, so they are challenged to discern which are needed
  - Ask students to write a one-pager with responses to all of the closing prompts
- Adaptations for English learners:
  - Provide language support for science vocabulary (velocity, dimensional analysis, conversion factor, etc.)
    - This could be a poster in the room, handout, etc.
  - Repeat instructions, using various words to explain the tasks
  - Physically demonstrate placing faster objects toward one side of the number line and slower objects on the other side of the number line
  - Allow wait time for students to process questions and respond before moving on

Assessment/Check for Understanding

Formative Assessment

- Accuracy of the students' creation of the velocity line
- Discussion during the creation of the velocity line
- Questions asked by students as they are working on conversions
- *OPTIONAL:* Discussion and questions by students during the measurement and conversion of dimensions of the objects in the nanoscale images

Summative Assessment

- Accuracy of students' conversions of speeds to meters per second
  - 80% correct is considered a full understanding of how to convert double units using given conversion factors
  - **Scale Answer Key**

Object	Given Speed	Equivalent in m/s
Snail	1.3 cm/s	0.013 m/s
Leopard Tortoise	27.7 cm/s	0.277 m/s
Person walking	3 mi/h	1.34 m/s
Zamboni	9 mph	4.02 m/s
Usain Bolt	43.99 km/h	12.22 m/s
Cheetah	70 mph	31.29 m/s
Race car	200 mi/h	89 m/s
Earth's rotation	1000 mi/h	447.04 m/s
Earth's orbit	30 km/s	30000 m/s
Speed of light	3.0x10^5 km/s	3.0x10^8 m/s

  - Are mistakes made in the cancellation of units?
    - If so, review how to know which unit of a conversion factor goes on top/bottom of the fraction.
- Accuracy of students' conversions of dimensions using a conversion factor of the objects in the images
  - 80% correct is considered a full understanding of measuring size and using a created conversion factor
  - Are mistakes in precision?
    - Explain how rounding and accuracy of measurement can contribute to error in the final answer.
  - Are mistakes made in the cancellation of units?
    - If so, review how to know which unit of a conversion factor goes on top/bottom of the fraction.

Required resources

How the Nanoscale Measures Up | National Geographic Society - This is the source for the nanoscale photos and images in the slides for this lesson.
Image Citations linked on Speeding Objects document

Supplemental resources

Instructional Resources

- Ch 1 Lesson 3 Train Track Method for Unit Conversions

Background Resources on Nano

- NISE Network
- Research Triangle Nanotechnology Network

Resources for Collaboration and Activity Implementation

- Collaborative Classroom Management From Kindergarten to 12th Grade | Edutopia
- 8 Classroom Management Ideas from Students

Author comments

- Depending on the number of students in your class, you might choose to exclude certain objects from the number line activity or students might be doubled up on the items they have to hang.
- This plan can be shortened by setting the number line up with 10^x cards attached before students come to class.
- This plan can be shortened by excluding the computation of dimensions of the nanoscale images displayed.
- Velocity Line Activity adapted from size and scale number line activity in *Extreme science: From nano to galactic.*

Sources

Jones, M. G., Taylor, A. R., & Falvo, M. R. (2009). *Extreme science: From nano to galactic*. NSTA Press.

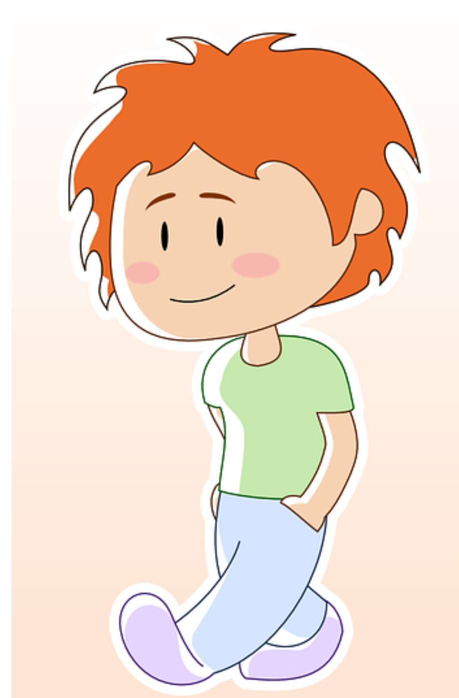
National Geographic Society. (2015, August 7). *How the nanoscale measures up*. National Geographic Society. Retrieved June 24, 2022, from https://www.nationalgeographic.org/activity/how-nano-scale-measures/

Appendices

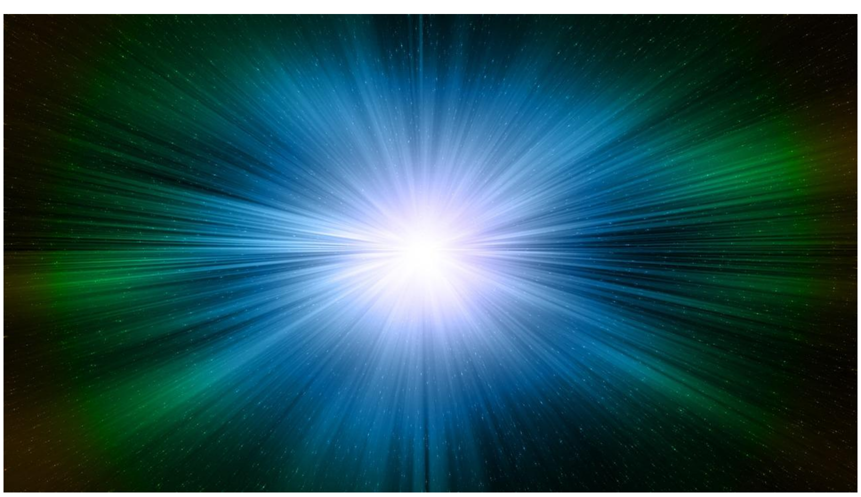
Speeding Objects: Cut out each object (option to paste on construction paper for stability)

Links to image sources on Speeding Objects document

Snail

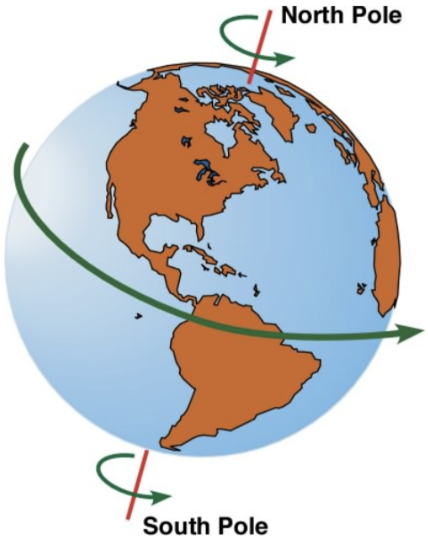


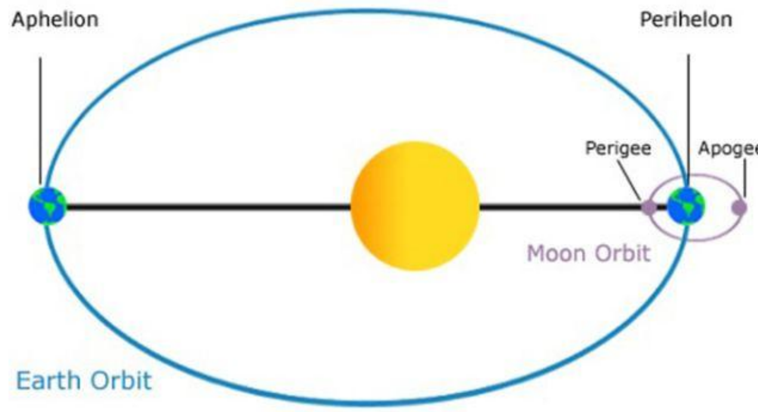
Child Walking



Speed of Light

Race Car





Earth's Rotation

Earth's Orbit

Usain Bolt

Zamboni

Cheetah

Leopard Tortoise

NOTE: All images pulled from Google Docs Insert Image from the Web tool

Speeds of Speeding Objects: to be cut out and hung on velocity line

1.3 cm/s

3 mi/h

9 mph

43.99 km/h

70 mph

200 mi/h

1000 mi/h

30 km/s

$3.0x10^5$ km/s

m/s Scale: to be cut out and hung on velocity line

10^{-9} m/s

10^{-6} m/s

10^{-3} m/s

10^{-2} m/s

10^1 m/s

10^0 m/s

10^1 m/s

10^2 m/s

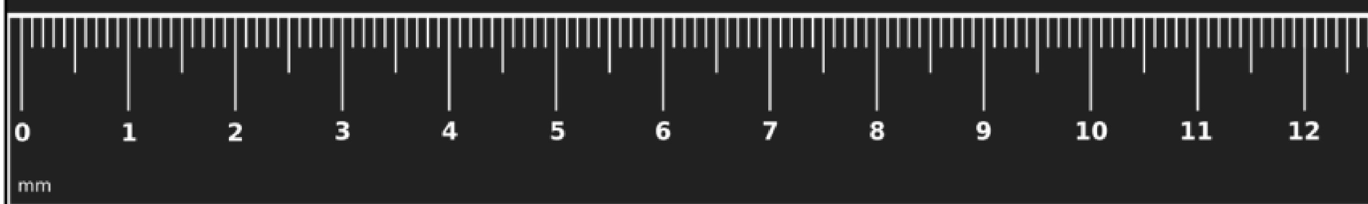
10^3 m/s

10^6 m/s

10^9 m/s

Photos of *Very* Small Things

But how small??

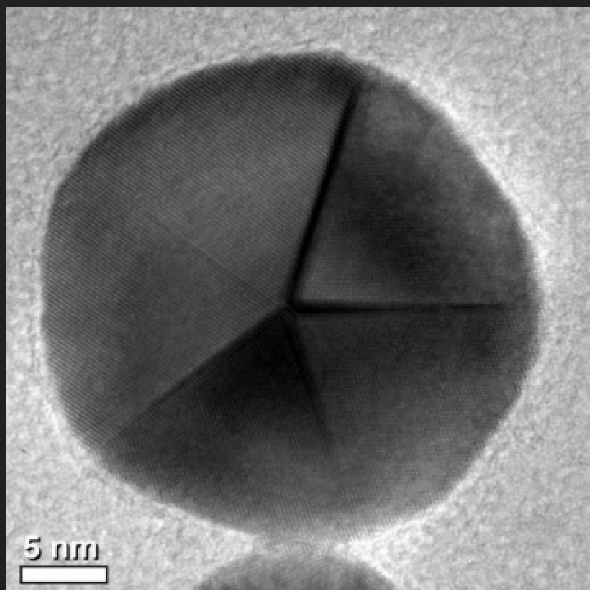


Instructions

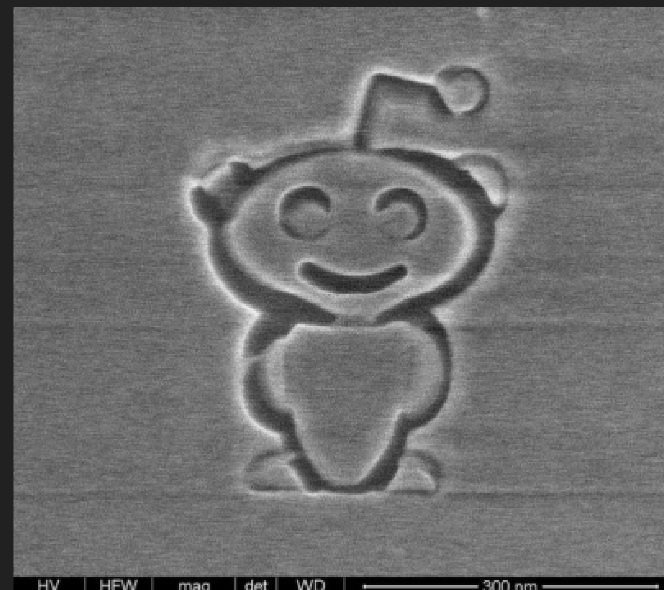
1. Locate the scale on the image you will measure
    a. What unit is given?
    b. How many units are given?
2. Take out your ruler and measure the scale
    a. Write a conversion factor for the image
    b. You may use centimeters, inches, or feet as one unit of your conversion factor.
3. Measure the height and width of the object in the image.
    a. How many units did you measure?
    b. Convert that number to nanometers, millimeters, centimeters, and meters. (Start by using your conversion factor.)

Each of the following images is from https://www.nationalgeographic.org/activity/how-nano-scale-measures/

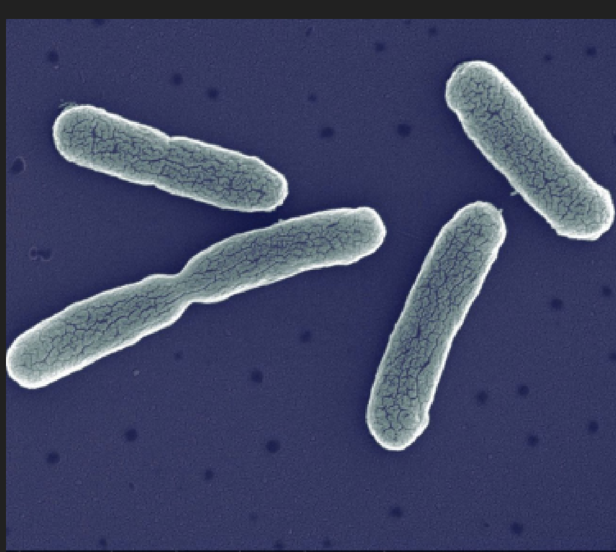
Gold Particle



Alien etching (done by electron beam)

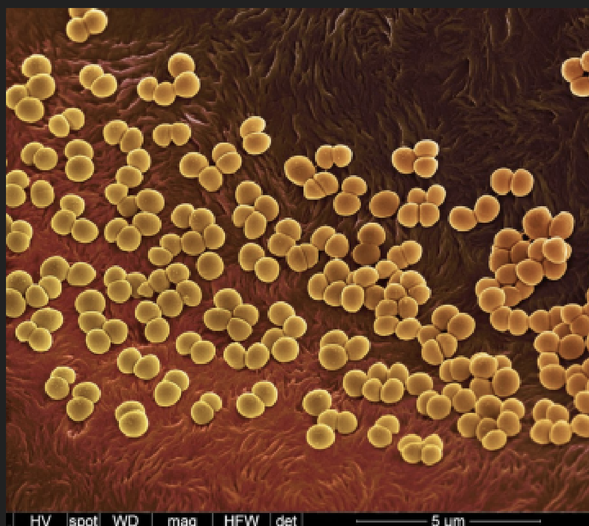


E. coli

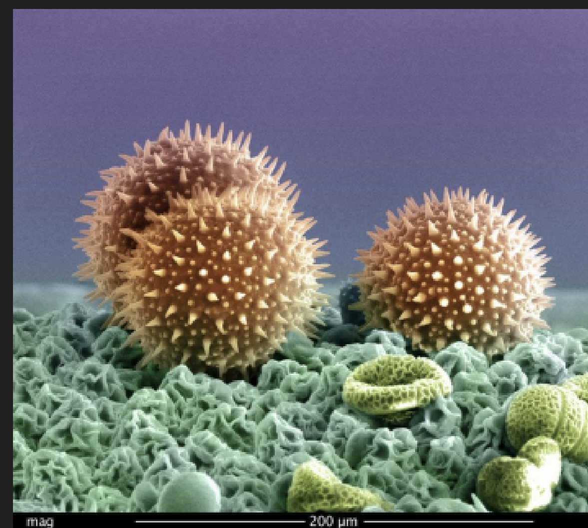


Ant head

MRSA on a bandage



Pollen of a Birch Tree on a stigma of a passion flower



Closing thoughts: Why does this matter?

Answer one of the following questions mentally, and be prepared to share.

1. Why is it important to know the scale of a given number value?
2. Why might it be useful to look at and talk about objects on the nano-level?
3. What are some different examples of applications of using technology to look at nanoscale objects?