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# Physics 0

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# The Physical Universe

Physics describes things that are much too small to see and much too large to visit. To keep track of such a huge range, scientists use powers of ten. A power of ten tells us how many zeros are involved.

For example,  $10^3 = 1000$ , while  $10^{-3} = 1/1000$ . The prefix *milli* means  $10^{-3}$ , *micro* means  $10^{-6}$ , and *nano* means  $10^{-9}$ .

An *order of magnitude* is a change by about a factor of ten. A bacteria that is  $1\text{ }\mu\text{m}$  across is about one thousand times smaller than a grain of sugar that is 1 mm across.

## 1.1 A map of length scales

Follow the same rule used in the presentation: every labeled step is  $10^3 = 1000$  times the one before it. The two collections below use the original lesson graphics.

Figure 1. Length scales from a grain of sugar to California

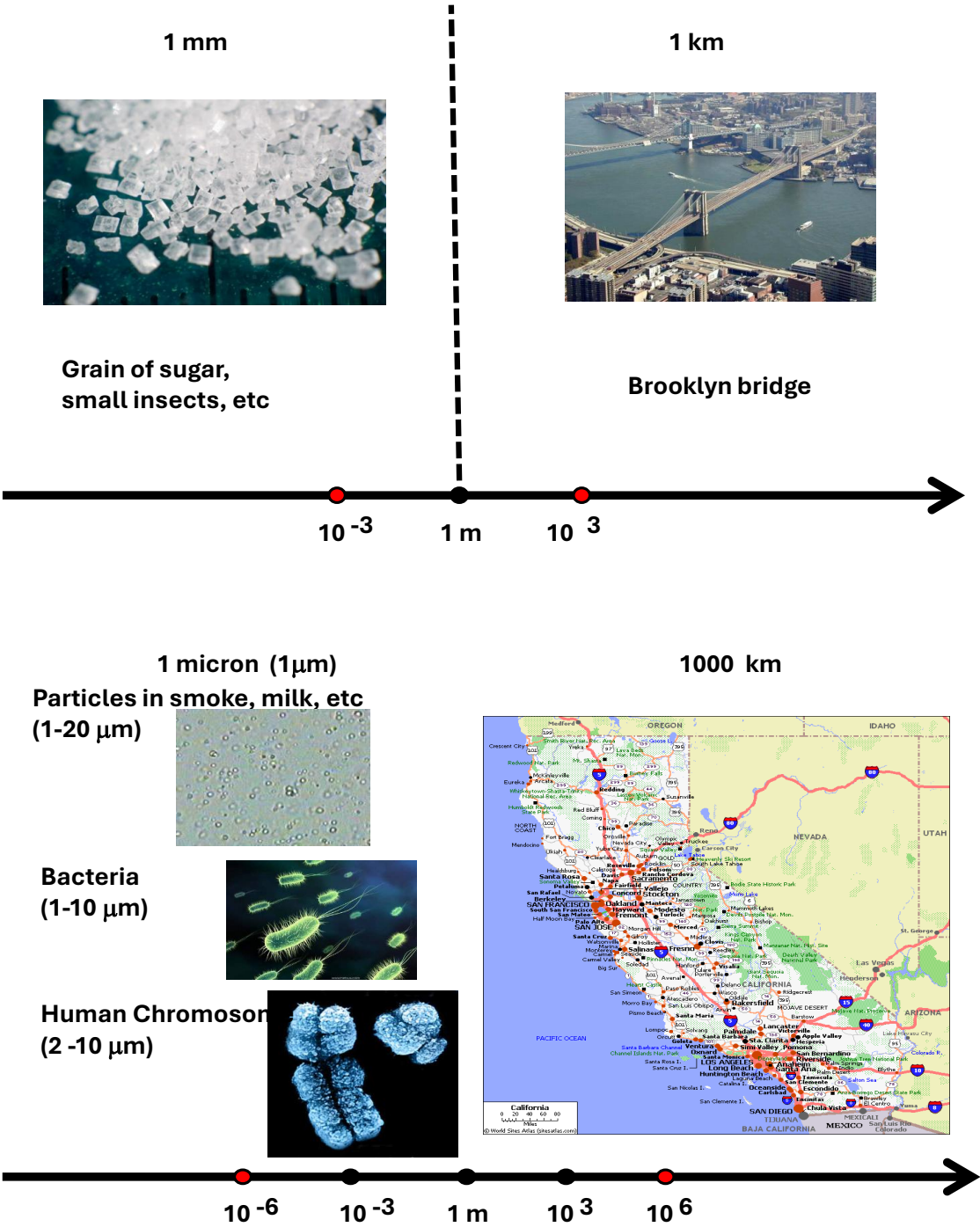
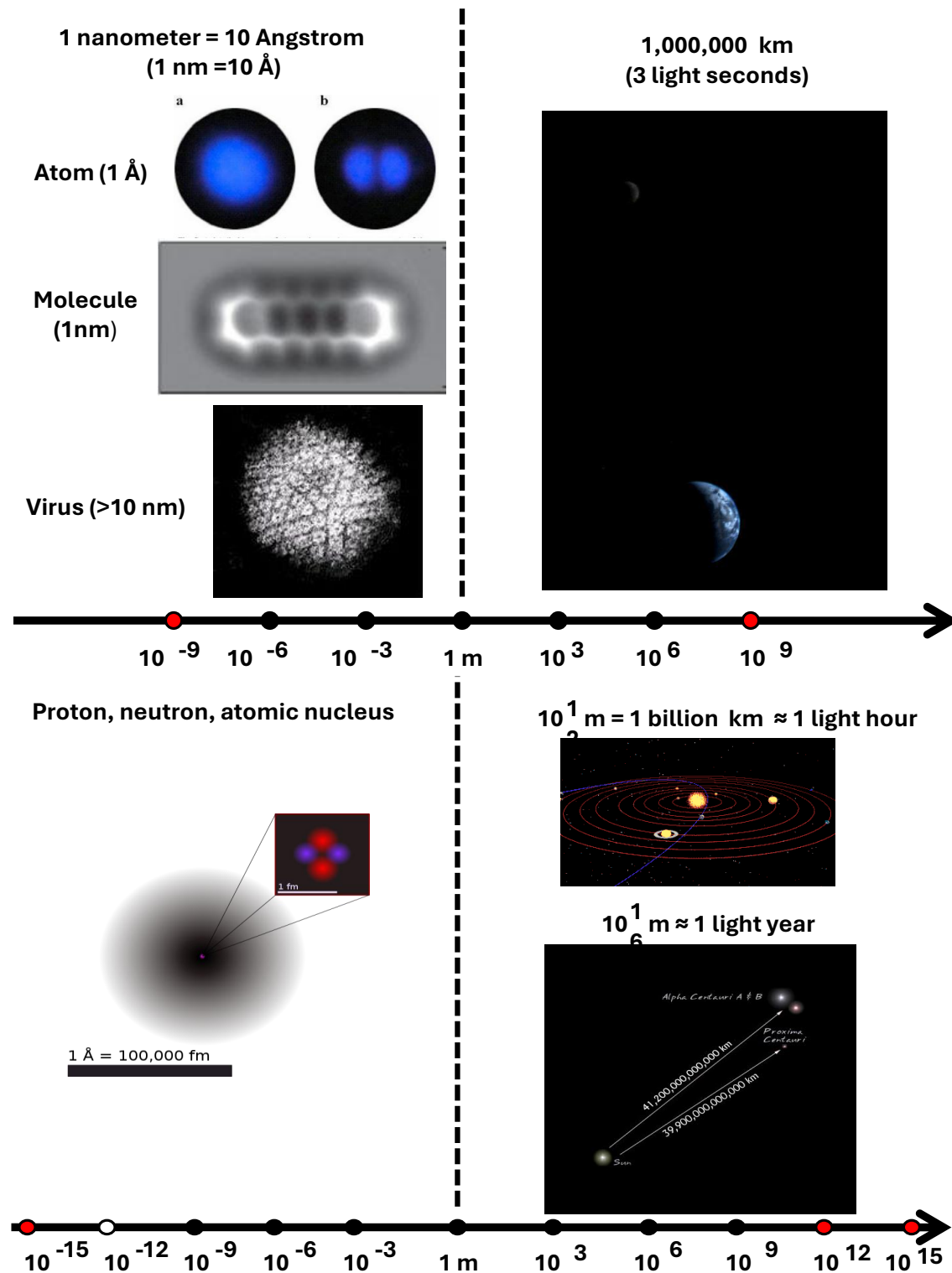


Figure 2. Length scales from nuclei to nearby stars



**Watch the scale change.** These short films zoom from human-sized objects toward the very small and toward the vast universe. **Classic version:** [Powers of Ten \(1977\)](#). **HD version:** [Modern HD variation](#).

## 1.2 A Short History of Physics

Physics grew from people asking simple questions. Why do objects fall? How do planets move? What is light? What is matter made of? Each new answer gave people a better way to describe the world.

### 1.2.1 A brief timeline

Table 1.1: Some major turning points in physics.

| When           | What changed                                                                                                                                                                     |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Around 350 BCE | Aristotle wrote influential ideas about motion and the natural world. Many of his claims were later tested and corrected.                                                        |
| 1600s          | Johannes Kepler described the paths of planets. Galileo Galilei studied falling objects and motion. Isaac Newton combined these ideas into laws of motion and universal gravity. |
| 1700s–1800s    | The Industrial Revolution raised practical questions about machines, heat, and energy. Scientists developed optics, thermodynamics, and electromagnetism.                        |
| 1905–1915      | Albert Einstein developed special relativity, which changed how physicists think about space, time, and light, and general relativity, the modern theory of gravity.             |
| 1925           | Modern quantum mechanics gave scientists a new language for atoms, light, and tiny particles.                                                                                    |
| 1905–1975      | Experiments and quantum ideas led toward the Standard Model of particle physics. Its modern form took shape mainly in the 1960s and 1970s.                                       |

### 1.2.2 How science moves forward

Scientists make observations and test models. A model earns trust when it correctly predicts what will happen. Newton’s laws work very well for bicycles, bridges, and planets. Relativity and quantum mechanics are needed at extreme speeds, in strong gravity, or for very small objects.

Older theories remain very useful within the ranges where experiments have tested them.

## 1.3 Particles and Big Questions

### 1.3.1 The Standard Model

Everything familiar around us is made from a small set of particles. The Standard Model is the best-tested map of those particles and three of the four known fundamental interactions. Quarks build protons and neutrons. Electrons belong to another family called leptons. Photons, gluons, and the  $W$  and  $Z$  particles carry forces between particles.

The Standard Model has passed many demanding tests, but it does not include gravity and it does not answer every question.

### 1.3.2 Dark matter

Galaxies spin and bend light as if they contain more mass than we can see. Physicists call this missing, unseen material *dark matter*. “Dark” does not mean evil or empty. It means that it does not shine or reflect light in the usual way. We know its gravity affects stars and galaxies, but we do not yet know what dark matter is made of.

### 1.3.3 Dark energy

The universe is expanding. Measurements show that this expansion is speeding up. Physicists use the name *dark energy* for whatever causes this speeding up. It may be a property of empty space, a new kind of energy, or a clue that our theory of gravity needs improvement.

**Two big open questions.** What is dark matter? What causes the speeding-up expansion of the universe? These questions are open because scientists have strong evidence for the effects, but no final explanation yet.

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# Kinematics

Kinematics is the study of motion. It answers questions such as: How far did an object move? How long did the motion take? How fast did the object move, and in which direction? In this chapter, we describe motion before asking what caused it.

## 2.1 Distance, time, and average speed

Distance, written as  $d$ , tells us how much ground an object covers. Travel time is the change between a final time and an initial time:

$$\Delta t = t_{\text{final}} - t_{\text{initial}}.$$

The Greek letter  $\Delta$  (delta) means “change.” The average speed is total distance divided by travel time:

$$v_{\text{avg}} = \frac{d}{\Delta t}.$$

Speed has no direction. A speed of 5 m/s means that, on average, an object covers 5 m every second. It does not tell us whether the object moves left, right, up, or down.

The SI unit of length is the metre (m), and the SI unit of time is the second (s). Therefore the SI unit of speed is metres per second (m/s). Other useful units include kilometres per hour (km/h) and miles per hour (mph).

Table 2.1: Common quantities and units for describing motion.

| Quantity                | SI unit    | Other useful units                |
|-------------------------|------------|-----------------------------------|
| Length or distance, $d$ | metre (m)  | kilometre, centimetre, mile, foot |
| Time, $t$               | second (s) | hour (h)                          |
| Speed, $v$              | m/s        | km/h, mph, cm/s                   |

## 2.2 Position, displacement, and average velocity

In one-dimensional motion, choose a positive direction and describe the object’s position with a single coordinate  $x$ . The displacement is the change in position:

$$\Delta x = x_f - x_i.$$

Average velocity is displacement divided by travel time:

$$\vec{v} = \frac{\Delta x}{\Delta t}.$$

Distance and displacement are different. Distance counts every part of the path. Displacement compares only the final position with the initial position. Velocity includes direction, while speed does not.

For example, if a student walks 50 m east and then 50 m west, the distance travelled is 100 m, but the displacement is 0 m. The average velocity for the whole trip is therefore zero, even though the average speed is not zero.

## HOMEWORK 3

- 1. Acela average speed.** An Acela train travels from Washington, DC to New York City according to the schedule below.

| Station        | Distance from Washington | Departure time |
|----------------|--------------------------|----------------|
| Washington, DC | 0 mi                     | 5:00 am        |
| Baltimore      | 41 mi                    | 5:30 am        |
| Philadelphia   | 135 mi                   | 6:30 am        |
| New York City  | 226 mi                   | 7:42 am        |

Find the average speed for each of the three segments and for the whole trip. First express each answer in mph, then convert it to km/h and m/s. Use  $1 \text{ mi} \approx 1.6 \text{ km}$ .

- 2. Dog on a walkway.** A straight walkway connects a house with a beach. A dog runs toward the beach at  $4 \text{ m/s}$  for 5 minutes. The dog then turns around and runs toward the house at  $3 \text{ m/s}$  for 10 minutes. Take the direction toward the beach as positive.
- Find the total distance travelled.
  - Find the displacement.
  - Find the average speed and the average velocity for the whole trip.
- 3. Measure a speed.** Measure the speed of a moving object, such as a toy car, a raindrop on a window, or a pet. Sketch the experiment, record the distance and time, and calculate the average speed in the units you used and in m/s.