Phys 100: The Physical World
Chapters 2 & 3

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Course Goals

Physics 100 is designed to introduce students to the foundational ideas and methods of physics, with an emphasis on conceptual understanding and real-world relevance. The course aims to cultivate scientific thinking by exploring the underlying principles that govern natural phenomena, from motion and energy to electricity, magnetism, and the structure of matter.

Students will develop their ability to reason quantitatively and qualitatively, engage with evidence-based explanations, and connect physics to everyday experiences. Through hands-on activities, problem-solving, and discussions, the course encourages curiosity, critical thinking, and a deeper appreciation for the role of physics in shaping our understanding of the modern world.

Meet Your Instructor

I'm Dr. Aaron Wirthwein, and I'll be your guide through physics this summer. I'm a college professor with a passion for helping students learn physics and *think like physicists*. My own research has focused on quantum systems—particularly *Bose-Einstein condensates*, where principles of quantum mechanics reveal themselves on large, observable scales.

In the classroom, I help students connect big ideas to everyday experience. Whether we're discussing motion, forces, or the nature of energy, I aim to create a learning environment that is clear, challenging, and rewarding. Outside of physics, I'm a parent, a tutor, and someone who believes deeply in the value of understanding how and why the world works the way it does.

Course Structure

1. All lectures will be online and recordings will be available on Brightspace. Lecture is the best place to ask questions and the only place to participate in discussion activities.
2. Homework will be due roughly once per week. Think of the homework as "guided learning" and practice for the exams.
3. There will be three 60-minute midterm exams and one 80-minute final exam consisting of multiple-choice, fill-ins, and short-answer questions (similar to homework).
4. Please reach out to Joseph Vandiver (vandiver@usc.edu) regarding all questions about the laboratory component of the course.
5. Grading is done by the distribution curve of the combined scores of homework, exams, and lab. Students taking the course Pass/No Pass must reach a minimum overall score of 70% to pass the course, regardless of how letter grades are assigned.

The Big Ideas of Physics

1. *The laws of physics are "universal."*
2. *Conservation laws constrain interactions.*
3. *Electricity and magnetism are unified.*
4. *Some processes are irreversible.*
5. *Nature is fundamentally probabilistic.*
6. *The laws of physics are frame independent.*

Textbook Sections

2.1 Aristotle on Motion

2.2 Galileo's Experiments

2.3 Newton's First Law of Motion

3.1 Speed

3.2 Velocity

3.3 Acceleration

3.4 Free Fall

Ancient Greek Philosophy

Our concepts of matter and motion have evolved over time. Before 600 BC, the Greeks believed that nature was totally unpredictable, fate was determined by capricious gods, and truth could only be handed down by priests. People began to notice that some things are permanent (like mountains), some are constantly changing (like clouds), and others are cyclically changing between permanent patterns (stars, seasons, night and day).

Thales of Miletus (585 BC) introduced the idea that natural events have natural causes. Plato (427 BC) emphasized the importance of abstract reasoning and ideal mathematical forms (Platonic solids). Aristotle (384 BC), a student of Plato, developed comprehensive physical theories on matter and motion that, thanks to St. Thomas Aquinas, later became Catholic dogma and ultimately set back science for nearly 500 years...

Aristotle (384–322 BC)

- Though a student of Plato, he diverged from Plato's idealism, favoring empirical observation and classification.
- Founded his own school, the Lyceum, where he worked on subjects akin to physics, biology, ethics, politics, logic, metaphysics, and more.
- Though many of his physical theories were eventually superseded (especially by Galileo and Newton), his emphasis on logic, classification, and observation laid a foundation for scientific methods.

Aristotle on Matter

He divided the universe into two realms: the sublunar (Earthly) realm, an imperfect world subject to change and decay, and the celestial (Heavenly) realm, which was perfect and unchanging. He rejected the idea of empty space (void) on logical grounds (since we can speak of it, it must be something, not nothing).

The elements are arranged by gravity into perfect spheres: earth (at the center), then water, air, and fire. A fifth element (quintessence) is found in the heavens: the ether. The five elements are continuous substances, although matter can have a minimal size.

Aristotle on Motion

Believed nature was purposeful and orderly, and every motion or change had a final cause (purpose). He defined natural motion as "the actualization of a potentiality." Everything has a natural state, and the *purpose of motion* was to return objects to their natural state. Two forces control natural motion: gravity is the tendency of heavy things to sink and levity is the tendency of light things to rise. Rocks sink in water, air bubbles rise in water, rain falls from the sky, and fire rises through air.

Motion that occurs against the natural tendency of an object is called violent (unnatural) motion. Violent motion requires a continuous external force (a mover) to be maintained. Aristotle believed that all motion occurs in some medium, and argued that the speed of an object must be proportional to the force applied and inversely proportional to the resistance of the medium.

Conceptual Question 1

Aristotle believed that heavier objects fall faster than lighter objects, with the speed of fall being proportional to the weight of the object. He also thought that the speed of fall is inversely proportional to the density of the medium through which the object falls.

What kind of motion would Aristotle say that a rock exhibits as it falls to the earth?

(a) Natural

(b) Violent

Conceptual Question 2

According to Aristotle, if you drop a heavy rock and a light rock from the same height at the same time, the heavy rock will hit the ground first. Now imagine dropping the two rocks while glued together. Aristotle says the combined object falls

(a) faster than the heavy rock alone

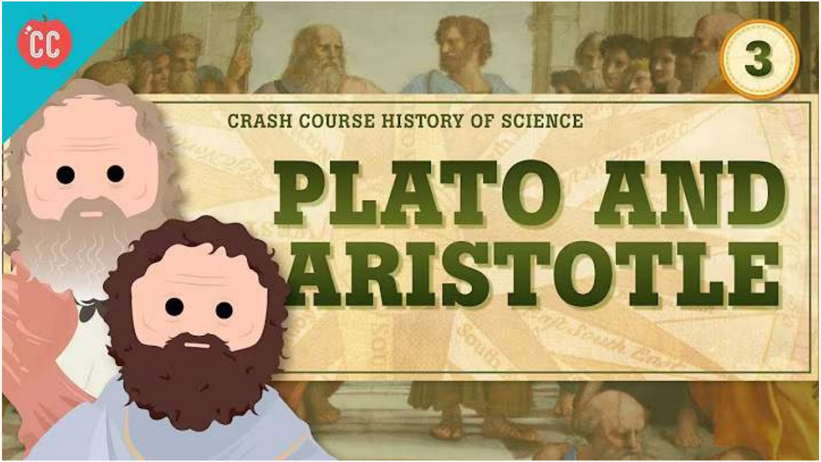
(b) slower than the heavy rock alone

(c) at the same rate as the heavy rock alone

Conceptual Question 3

A soccer ball is resting in the grass when you decide to give it a swift kick. The soccer ball first flies up into the air and then it falls down, bounces a few times, and eventually comes to rest in the grass. Write an explanation for this observed motion, starting from the very beginning, as if you were one of Aristotle's straight-A students. Type your response into the chat (public or private) and record it for your notes!

Socratics



Click here to watch video (12:28)

Pure Deduction vs Pure Induction

Deduction and induction are two primary types of reasoning. Deduction moves from general premises to specific conclusions (top-down), while induction moves from specific observations to general conclusions (bottom-up). While a deductive approach comes with logical rigor, internal consistency, and far-reaching generality, an inductive approach is grounded firmly in empirical reality and adapts to new data.

You might think that scientific reasoning should be purely inductive, but there are several problems: (i) the "inductive leap" is not guaranteed, (ii) it has limited predictive power, and (iii) it is susceptible to bias or incomplete data. A deductive approach can address these problems, but its primary weakness is that it can be detached from reality if the starting assumptions are flawed! How do we choose between different theories?

Modern Scientific Method

Pure deduction is logically perfect but potentially blind.
Pure induction is empirically grounded but potentially shallow.

Modern science thrives by combining Plato's love of structure with Aristotle's respect for nature. It starts with observations, builds theories and models using mathematics and logic, tests predictions against new data, and refines the models if necessary.

The scientific method is a hypothetico-deductive method that evolves through a combination of creativity, logic, and experimental feedback. For our purposes, a scientific explanation is a reasoned account of a natural phenomenon, supported by evidence and logic, that can be tested and refined through observation and experimentation. Scientific explanations aim to connect theories with specific observations.

Conceptual Question 4

Which of the following best represents a scientific explanation for why plants grow taller in sunlight? Select all that apply.

(a) Plants always strive to be as happy as possible, and sunlight makes plants happier.

(b) Plants in sunlight grow taller because they receive more energy through photosynthesis, which supports cell growth and division.

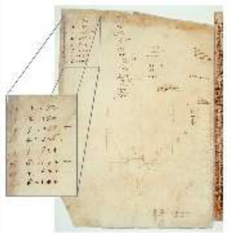
(c) Plants grow taller in sunlight because that's just how nature works.

(d) Plants in sunlight grow taller because they have more time to grow during the day.

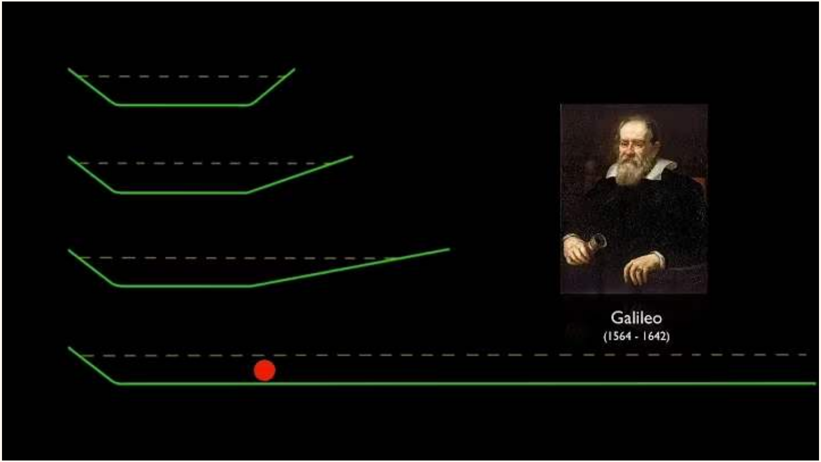
Galileo Galilei (1564-1642)

Italian physicist, astronomer, and philosopher who helped launch the Scientific Revolution. Made groundbreaking contributions to motion, astronomy, and scientific methodology–challenging centuries of Aristotelian thought.

He emphasized the importance of mathematical laws and empirical testing over speculation. Blended inductive observations with deductive reasoning. His commitment to reason, observation, and experimentation over authority earned him a lasting place as a symbol of scientific courage and intellectual freedom.



Galileo's Thought Experiment



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Conceptual Question 5

The use of inclined planes helped Galileo

(a) eliminate the acceleration of free fall.
(b) discover the concept of energy.
(c) discover the property called inertia.
(d) discover the concept of momentum

The Property of Inertia

Galileo reasoned that, in the absence of external forces (like friction or air resistance), an object would continue to move at a constant speed. This was a major departure from Aristotle's view, which held that objects needed a continuous force to keep moving. Galileo used a form of extrapolation, a process of extending known observations beyond the range of direct experience, in order to arrive at his conclusion.

Inertia is a property of matter to resist changes to its state of motion. Aristotle did not recognize the idea of inertia because he failed to imagine what motion would be like without friction. It is a common misconception that a continuous applied force is required to keep an object in motion. An object can remain in motion without anything acting on it whatsoever!

Isaac Newton (1642-1727)

English mathematician and natural philosopher who revolutionized physics with his laws of motion and universal gravitation. Created a unified framework that could explain motion both on Earth and in the heavens.

His key insight was that a small set of well-chosen, general principles can generate a vast range of specific predictions. Building on Euclid's geometry, he co-invented the mathematical tools (calculus) that were needed to precisely formulate his ideas and make predictions.

"The architect of classical physics."

Introduction to Newton's Laws of Motion

Newton's laws **are**

(i) the starting assumptions of classical mechanics

(ii) universal descriptions of motion

(iii) quantitative and testable

Newton's laws **are not**

(i) explanations of why forces exist or why objects move in response to forces ("hypotheses non fingo")

(ii) valid at all scales or in all frames of reference

(iii) complete without additional information

What is a Force?

Click here to watch video (3:40)

Conceptual Question 6

"A force is a push or a pull."

Using the definition of force above, what force(s) is (are) acting on you right now? Type your answer in the chat!

Newton's First Law of Motion

In the absence of forces, an object will continue in a state of rest or of uniform speed in a straight line.

(i) If an object is at rest, it will remain at rest.

(ii) If an object is moving, it continues to move without turning or changing its speed.

Newton's first law is often called "the law of inertia." The statement above is stronger than the one presented in your textbook, but further removed from direct experiences. How many objects have you seen to be *completely free of forces?*

The answer is none!

Inertial Frame of Reference

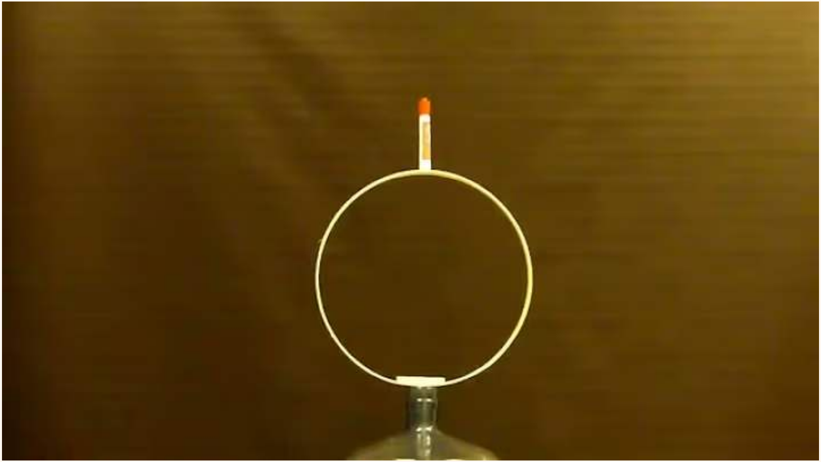
Newton's first law sets the stage for classical mechanics. In the most boring universe imaginable, an object free of interactions will either stay at rest or move with *constant speed* in a *straight line*. A frame of reference in which Newton's first law is valid is called an inertial frame of reference. Not all reference frames are inertial (more on that later).

According to the rules of logic, it follows from the first law that "if an object changes speed or deviates from a straight-line path, then it must **not** be absent of forces." [We call this the contrapositive–a statement formed by negating both the hypothesis and conclusion and then swapping their order.] Hence, in an inertial frame of reference, you will only ever observe an object change its speed or deviate from a straight-line path if there is at least one force (and possibly many) acting on it.

Tablecloth Experiment

Click here to watch video (0:42)

Slow Motion Inertia Demonstration



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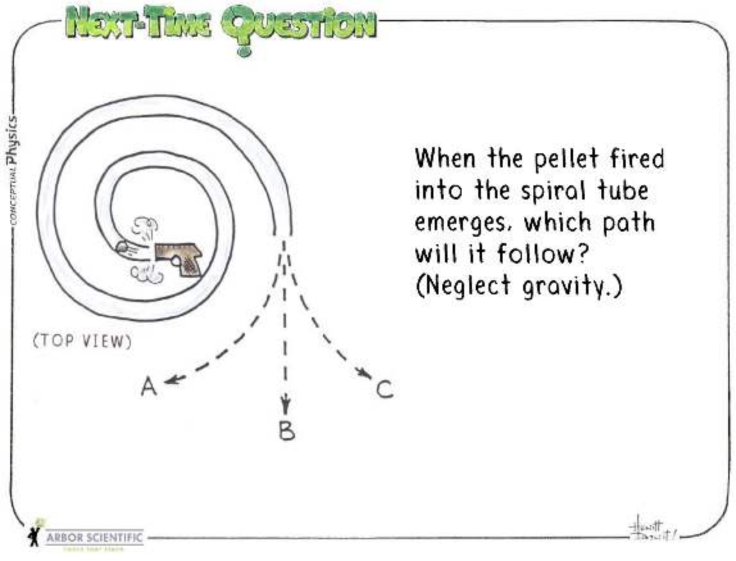
Conceptual Question 7



Speed

A hallmark of good science is the creation and use of precise definitions. Galileo was the first to consider a mathematical definition of motion, called speed, that measures the rate at which an object covers distance. In words,

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

It is perfectly reasonable to ask "how should we measure distances and time intervals?" In this class, we will take distance and time measurements for granted. Imagine every object is like a car, equipped with a clock, an odometer, and a speedometer.

Example: A girl runs 4 meters in 2 s. Her speed is 2 m/s.

Example 1

You're driving your car on a highway with a posted speed limit of 60 mph. Unfortunately, your speedometer has stopped working, but your odometer says that you travel 1 mile in the same time it takes your clock to advance by 1 minute. Are you breaking the speed limit, and how do you know?

What if your odometer measured 2 miles in a time interval of 2 minutes? Should you speed up, slow down, or continue at the same speed to drive at the speed limit? How about 3 miles in 180 seconds (note the units of time are different)?

Average vs Instantaneous Speed

We observe that objects can change their speed over time, sometimes moving faster and other times moving slower.

Instantaneous speed is the speed of an object at a particular instant of time (the reading on your speedometer at a certain time), whereas average speed is simply the total distance traveled divided by the total time of travel.

Average speed doesn't indicate the different speeds and variations that may have taken place, and the average speed can never be greater than the maximum speed.

$$\text{average speed} \leq \text{maximum speed}$$

"less than or equal to"

Conceptual Question 8

The average speed of driving 30 km in 1 hour is the same as the average speed of driving

(a) 30 km in $1/2$ hour.

(b) 30 km in 2 hours.

(c) 60 km in $1/2$ hour.

(d) 60 km in 2 hours.

Conceptual Question 9

An ambitious cyclist wishes to travel 40 km with an average speed of 40 km/h (24.8 mph). During the first 20 km, the cyclist manages to hold an average speed of 40 km/h. During the next 10 km, however, the cyclist averages only 20 km/h. To ride the remaining 10 km and average 40 km/h overall, the cyclist must ride at

(a) 60 km/h

(b) 80 km/h

(c) 90 km/h

(d) Faster than the speed of light!

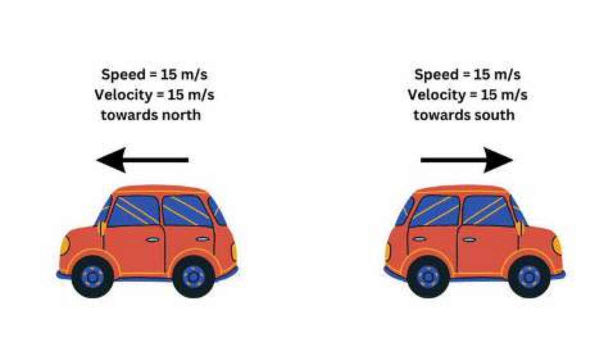
Example 2

Your electric scooter has a top speed of 10 meters per second (about 20 miles per hour). If it takes you 1 minute to ride down Trousdale Parkway, how far did you travel in that 1 minute?

What if you ride for 120 seconds? How far would you ride in half an hour? Hypothetically, if your scooter could carry enough charge in its battery, how far would you ride in one whole day?

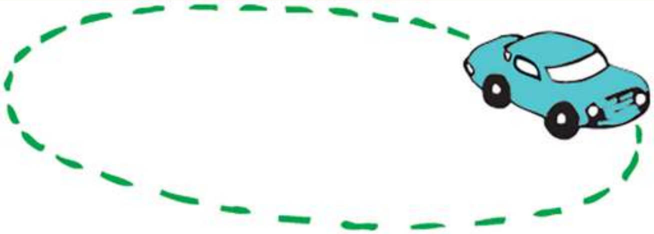
Speed vs Velocity

Speed tells you how fast an objet is moving, while velocity tells you how fast and in what direction. Remember, Newton's first law implies that forces are present whenever an object's speed or direction of travel changes, so the concept of velocity is crucial for understanding motion.



Changing Velocity

An object moving with constant velocity is moving with constant speed along a straight line. There are two ways an object can change velocity; (i) it can change its speed or (ii) it can change its direction of travel. Forces are present in both cases!



Acceleration

Acceleration, also introduced by Galileo, is a quantity that measures how quickly and in what direction the velocity changes. Humans are pretty good at discerning the positions of objects and we're even better at finding them when they move.

Acceleration is hard to see but easy to feel.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time interval}}$$

Example: Your car's speed at some moment of time is 40 km/h, and 5 s later it's 45 km/h. Your car's average acceleration is equal to 1 km/h/s (1 km per hour per second).

Conceptual Question 10

Which of the following components of a car could be considered an "accelerator" according to physics? Select all that apply.

(a) Gas pedal

(b) Break pedal

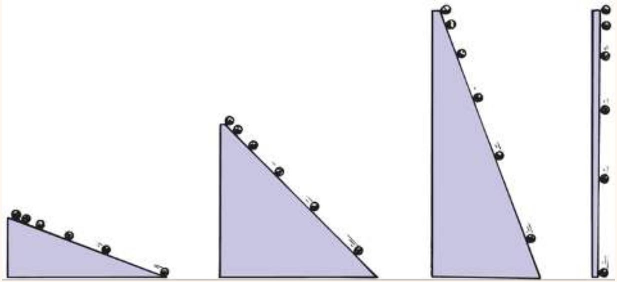
(c) Steering wheel

(d) Seatbelt

(e) Airbags

Acceleration Due to Gravity

Galileo increased the inclination of inclined planes. Steeper inclines result in greater accelerations. When the incline is vertical, acceleration is at maximum, the same as that of a falling object. When air resistance is negligible, all objects fall with the same unchanging acceleration–the acceleration due to gravity.



Galileo’s Inclined Planes

Click here to watch video (5:02)

David Scott on the Moon

Click here to watch video (0:52)

World's Biggest Vacuum

Click here to watch video (4:42)

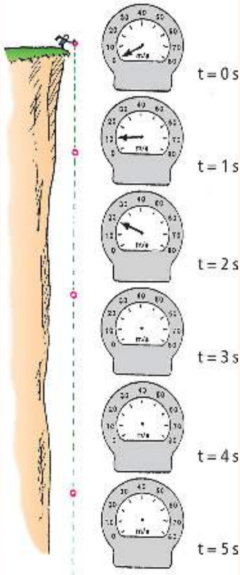
Free Fall

An object is said to be freely falling when it is under the influence of gravity only, with no air resistance. All freely falling objects on earth accelerate at the approximate rate of 10 m/s/s, that is $10\ \mathrm{m/s^2}$. [More precisely $9.8\ \mathrm{m/s^2}$, but we'll use $10\ \mathrm{m/s^2}$.]

This means that a freely falling object, regardless of its velocity at any moment, changes its velocity by 10 meters per second *toward the ground* every single second.

Example: if an object is heading down at 20 m/s, after one second, it will have a velocity of 30 m/s toward the ground. On the other hand, if an object is heading up at 20 m/s, after one second, it will have a velocity of 10 m/s away from the ground. In the next second, its velocity will be zero, and one second later, its velocity will be 10 m/s toward the ground. The acceleration has made it change speed and direction!

Velocity of a Falling Object



$$\text{velocity} = \text{acceleration} \times \text{time}$$

Time (s)	Velocity (m/s)
0	0
1	10
2	20
3	30
4	40
5	50

Notice that, since the speed is increasing, the rock covers more distance during each one-second time interval.

Distance of a Falling Object

If an object travels at constant speed, we can find the distance traveled by simply multiplying speed and time. Galileo found that the distance traveled by a uniformly accelerating object is proportional to the *square of the time.*

$$\text{distance} = \frac{1}{2}(\text{acceleration} \times \text{time} \times \text{time})$$

Time (s)	Distance (m)
0	0
1	5
2	20
3	45
4	80
5	125

Pitfall Prevention

Here is a passage from your textbook: "average speed... is the average of its initial and final speeds. To find the average value of these or any two numbers, we simply add the two numbers and divide the total by 2." The last sentence is true in general, but this procedure only works when the acceleration is constant.

$$\text{average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

$$\text{distance} = \text{average velocity} \times \text{time}$$

Conceptual Question 11

Sarah runs 2 laps of a 100-meter circular track at a constant speed of 6 m/s and then 1 lap at 3 m/s. What is Sarah's average speed over the course of her three-lap run?

(a) 4.0 m/s
(b) 4.5 m/s
(c) 5.0 m/s
(d) 5.5 m/s