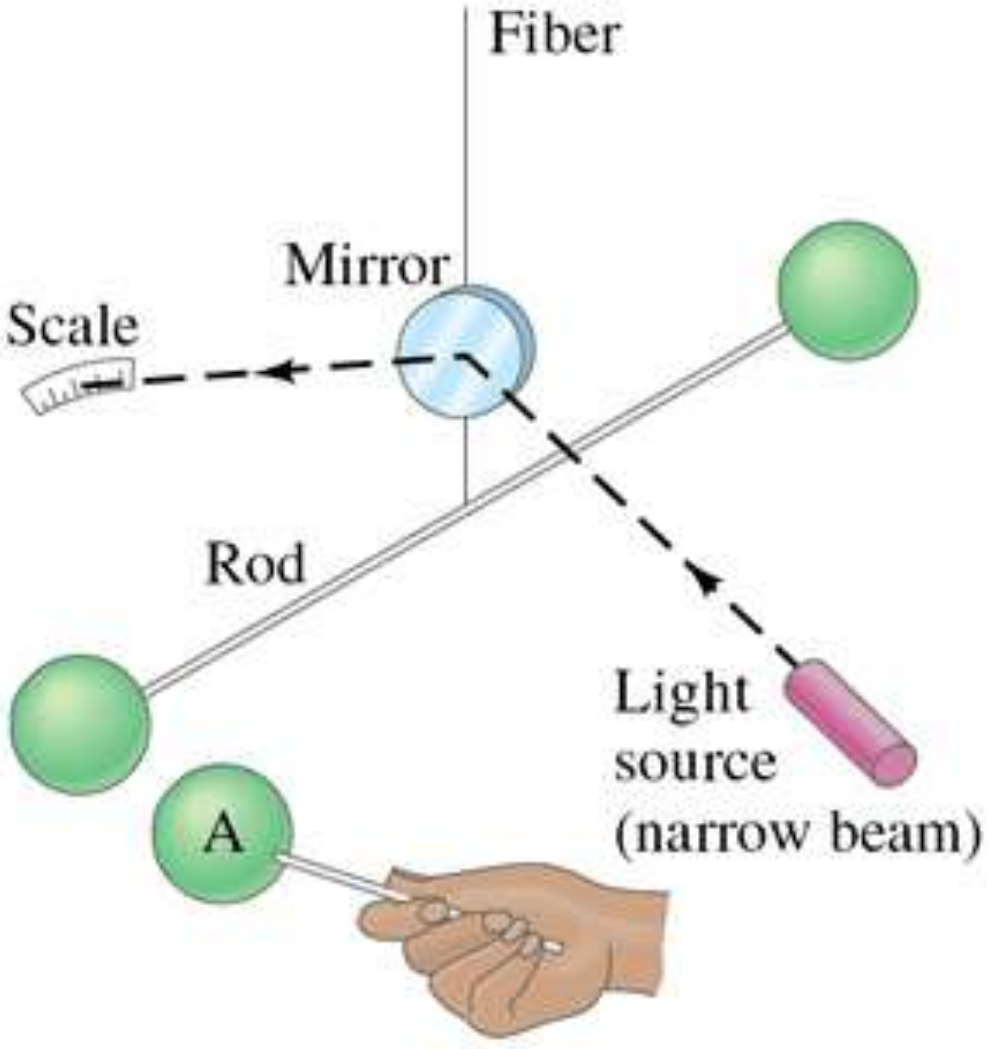
Cavendish Experiment: Direct measurement of *G*



Henry Cavendish
1797

Clicker Question

Which is ***false*** about the Cavendish experiment?

A. In the Cavendish experiment, it helps to use masses of large density as this allows the distance between masses to be reduced.
B. The Cavendish experiment helps us determine the mass of the Earth, if we know the Earth's radius and the acceleration of gravity.
C. The Cavendish experiment, performed on the surface of Mars, can tell us what Newton's gravitational constant is.
D. The Cavendish experiment, performed on a spacecraft falling into a black hole, would yield the same value for the gravitational constant as when performed on Earth.
E. If the Cavendish experiment were conducted on the moon, the gravitational acceleration of the moving masses would be about 1/6 of that measured on Earth.

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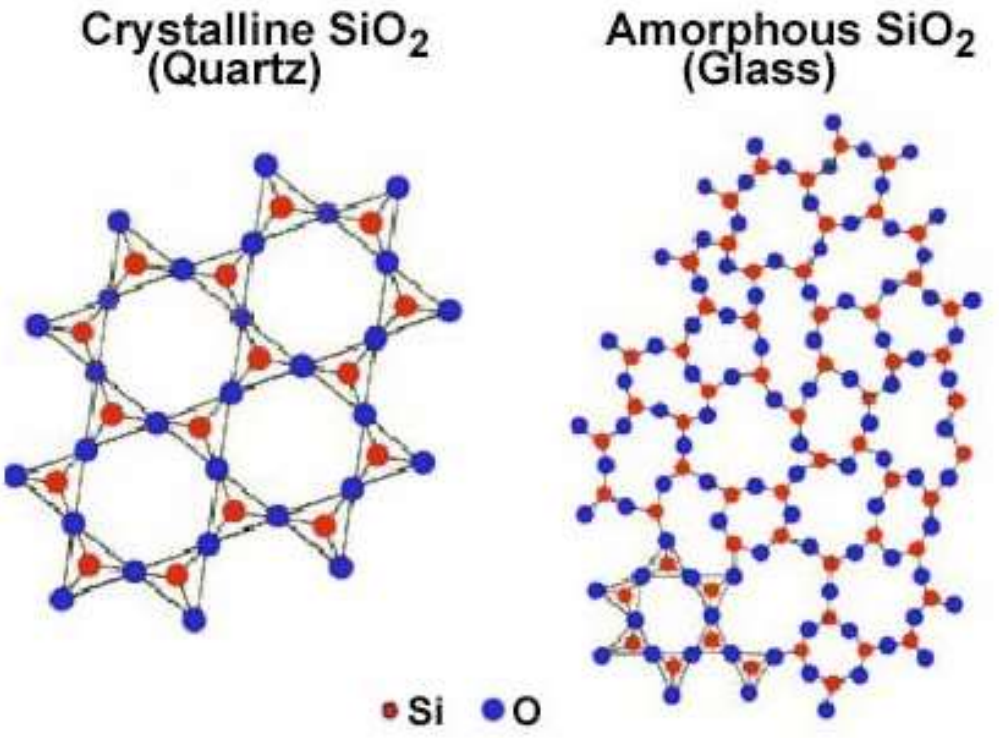
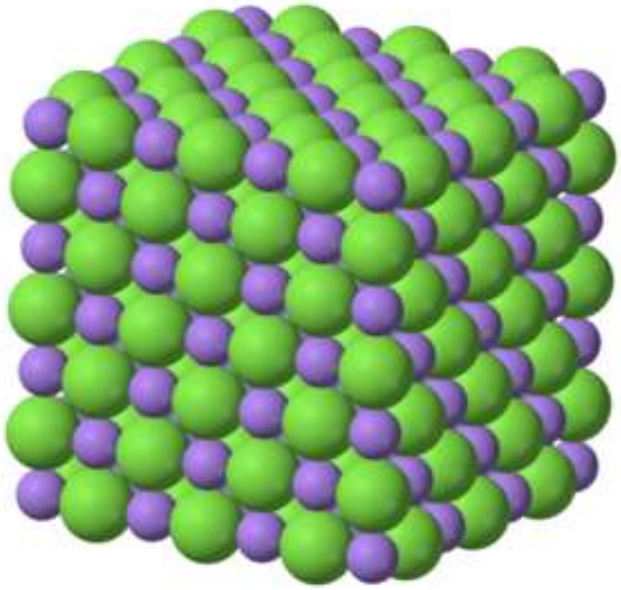
Recap: States of Matter

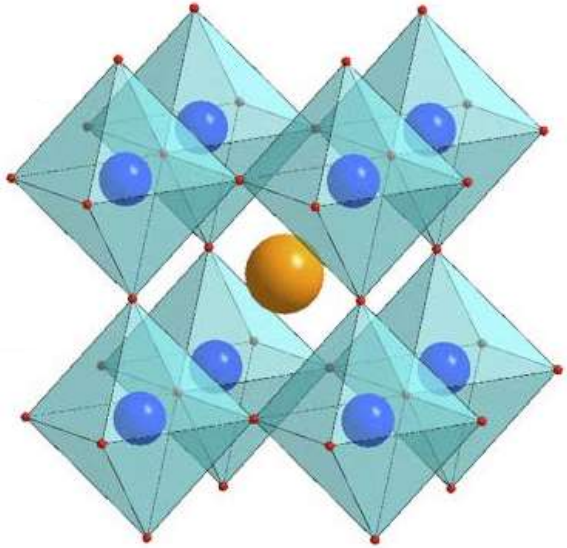
Solids

- Atoms are closely packed
- They vibrate around fixed locations
- The material is “rigid”
- Two variants:
  - Crystal
  - Amorphous



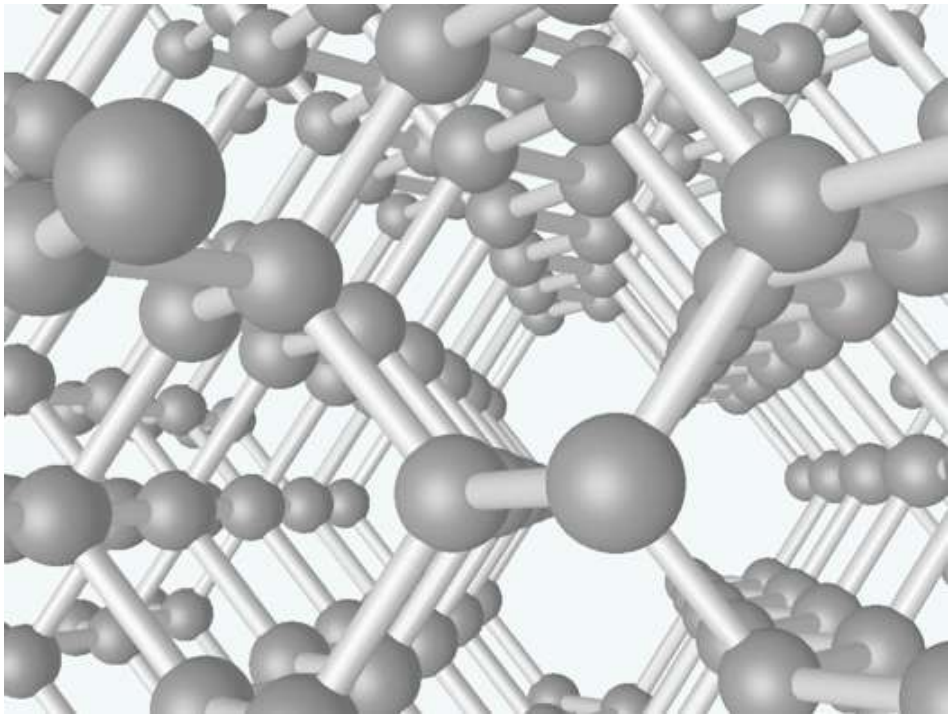
NaCl





Perovskite

($CaTiO_3$)



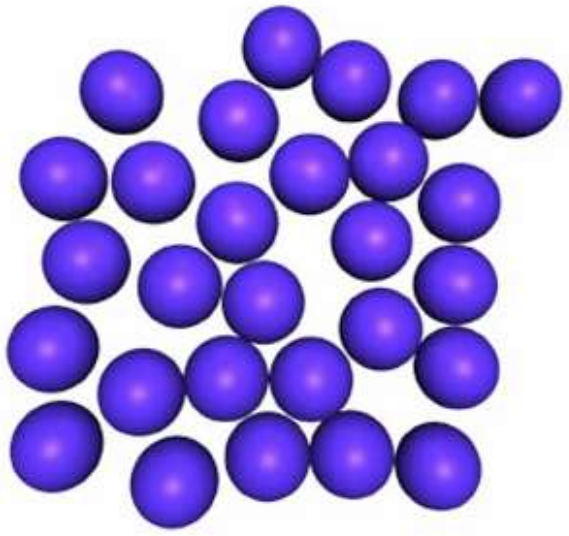
diamond

also: silicon

States of matter

Liquid:

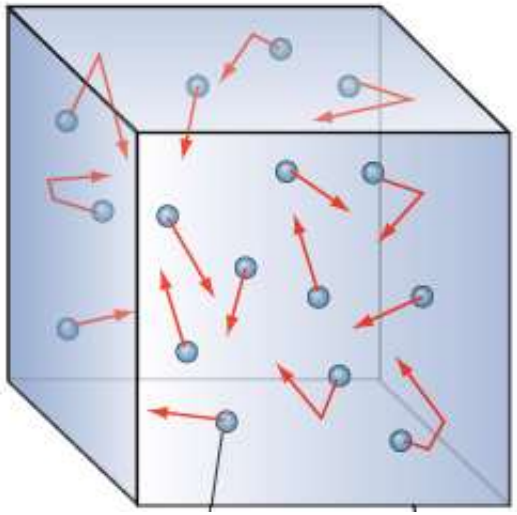
- Atoms are still closely packed.
- They move freely around one another.
- The material can “flow”.
- Volume is approximately fixed.



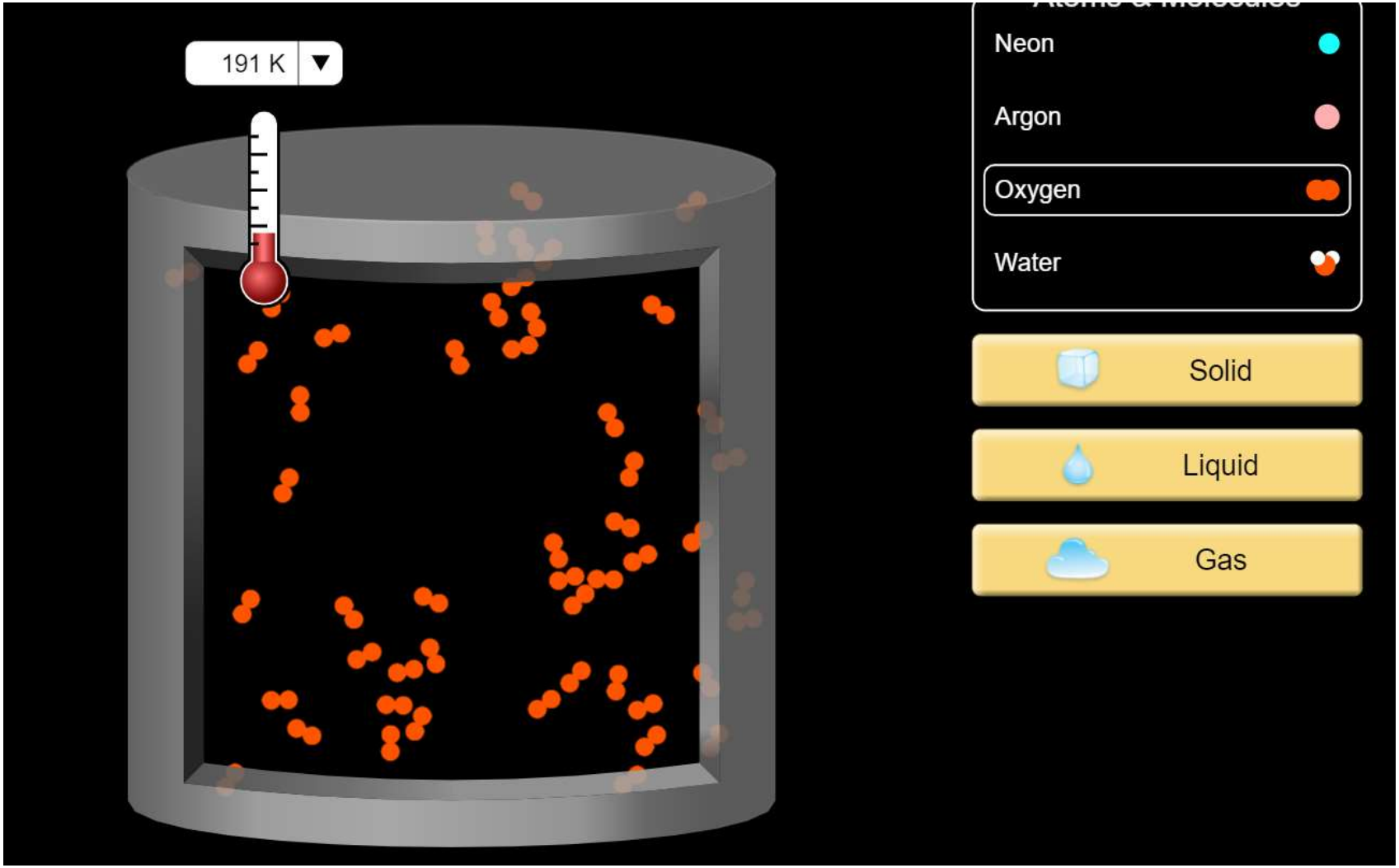
States of matter

Gas

- Atoms or molecules are far apart.
- They move freely between collisions.
- Gas expands to fill available volume.



Phase change simulation



Clicker Question

At the microscopic level, the difference between liquids and solids is that

A. There is at least ten times as much distance between the atoms of a liquid than in a solid.
B. In a liquid, the individual atoms are larger.
C. In a liquid, the individual atoms are squishy and can deform.
D. In a solid, the atoms are completely at rest – no motion at all.
E. The liquid's atoms move throughout the liquid, while the solid's atoms remain more or less fixed in place.

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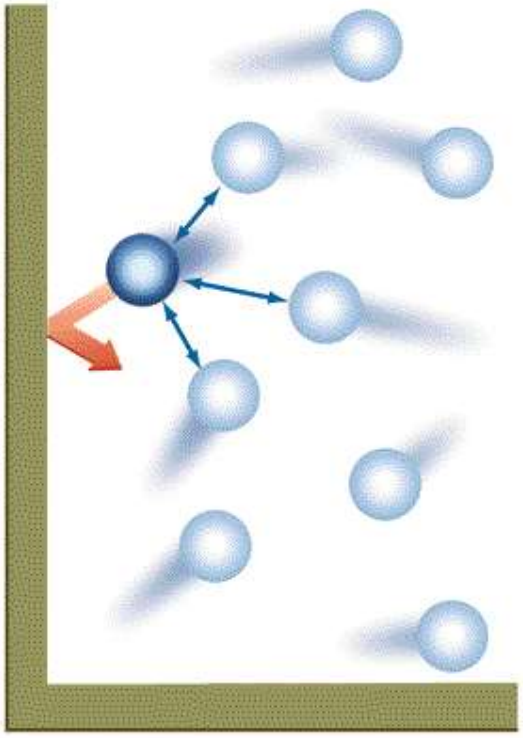
E. The liquid's atoms move throughout the liquid, while the solid's atoms remain more or less fixed in place.

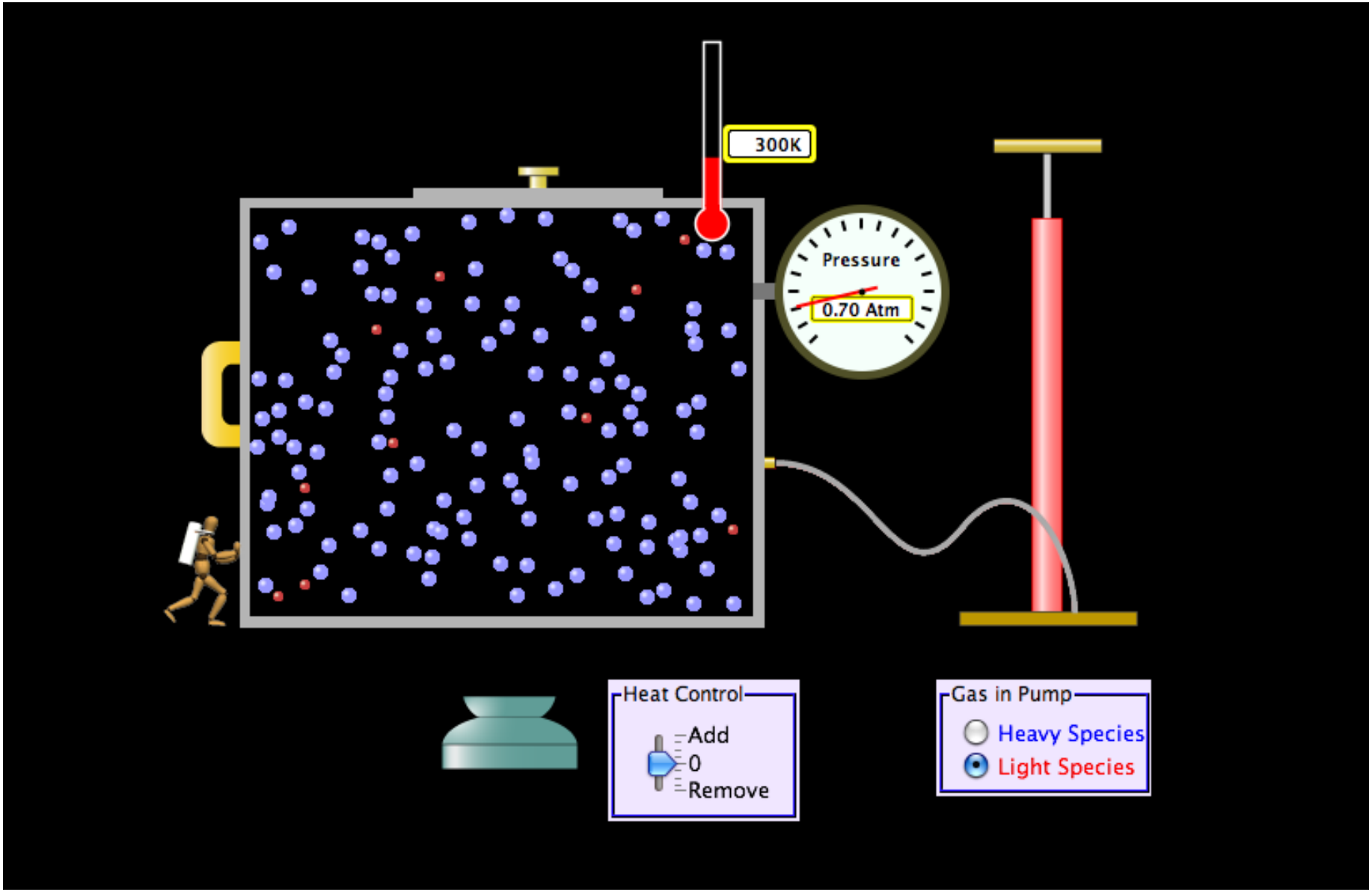
The amount of motion of molecules, whether in a solid, liquid, or gas, is a measure of the ***temperature*** of the substance.

As the molecules bounce off the walls of a container, they exert a ***pressure*** on them.

Pressure is outward force on the container, per unit area.



Properties of Gases



- Demo: Cooling helium with liquid nitrogen
- Effect of temperature on pressure/volume
- Buoyancy

- Demo: Liquid Nitrogen Cannon
- Phase change liquid to gas
- Effect of pressure

Vacuum: a complete absence of matter.

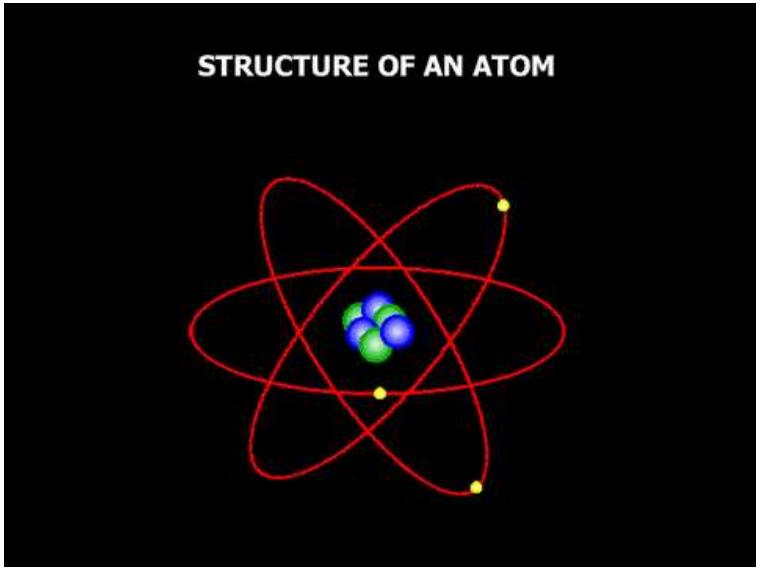
(A vacuum created on earth is never perfect; it is called a partial vacuum, as there are still some gas molecules present.)

Models of the Atom

- Greek model (300 BCE)
  - Tiny, indivisible, unchangeable
- Electric model (19th century)
  - Electrons inside.
  - They can be removed, leaving charged ions.
  - Almost all the mass is in the positive ions.
  - Explains electrical conduction.
  - Helps explain chemistry.

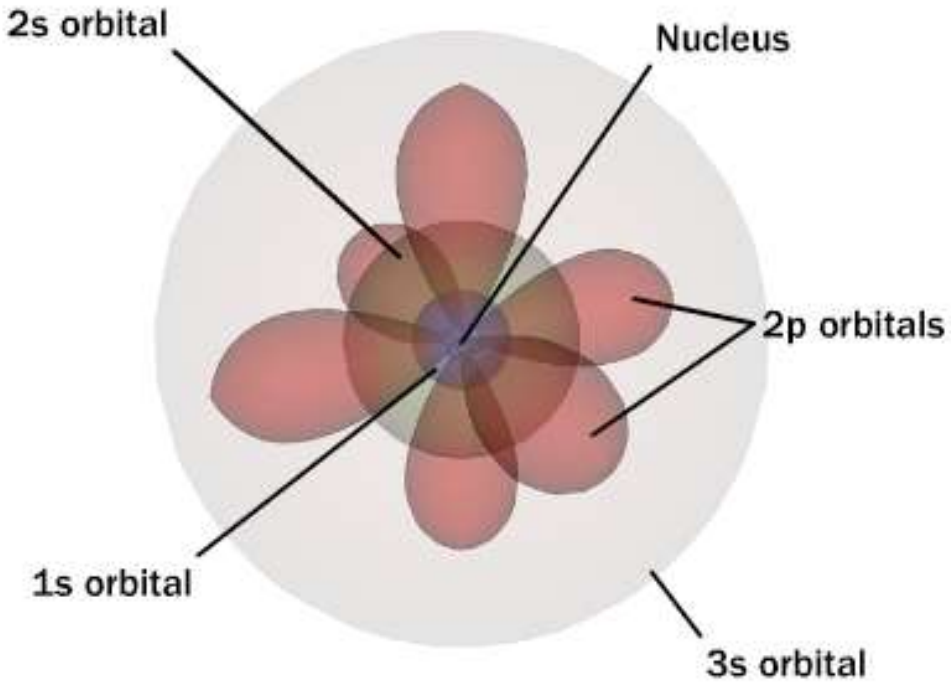
Models of the Atom

- Planetary model (Early 20th century)
  - Nucleus is tiny and massive
  - Light electrons in orbit around nuclei
  - Atoms are mostly empty space



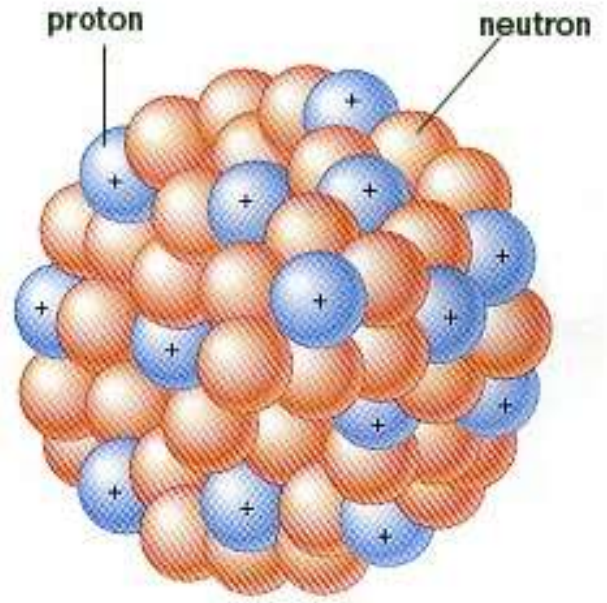
Models of the atom

- Quantum model (Mid 20th century)
  - Electrons do not have definite orbits
  - Instead, they occupy fuzzy “orbitals”



Atomic Nucleus

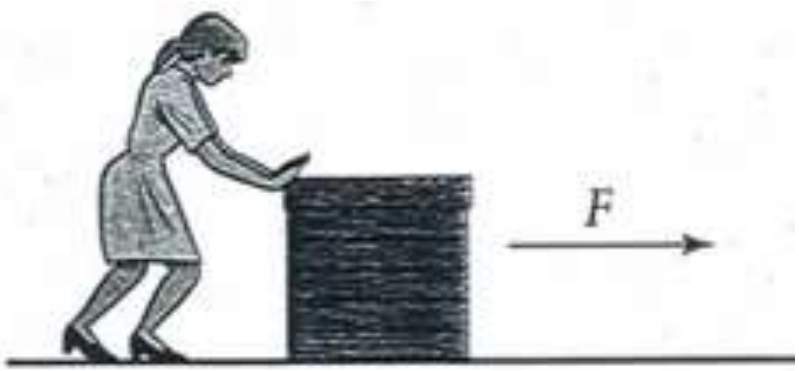
- Made of neutrons and protons
- Explains “isotopes”
- Explains “fusion” and “fission”
- Nuclear energy…

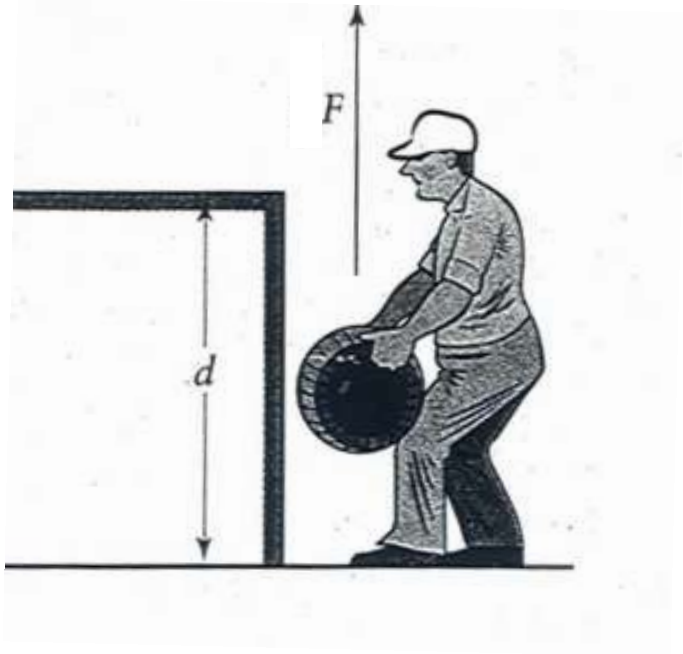


Work

"Work" has a special meaning in physics.

Consider the following situations:





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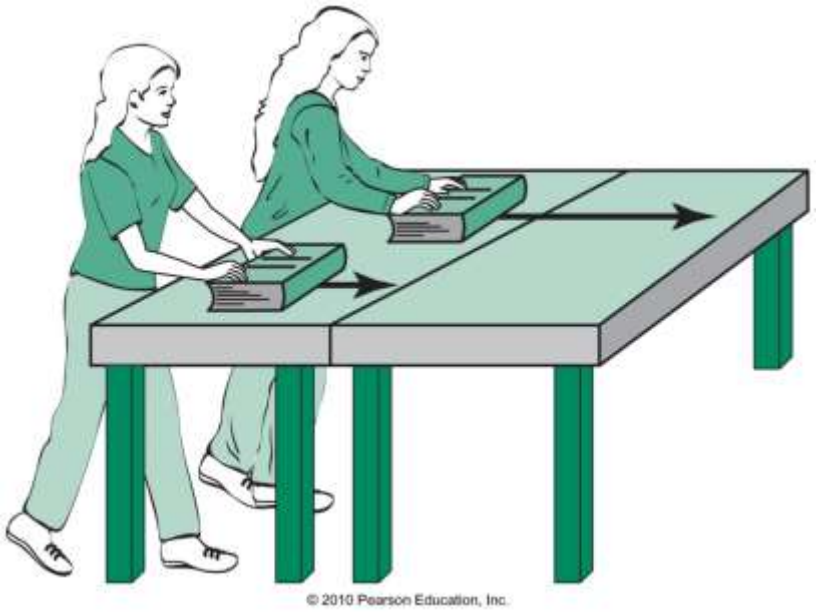


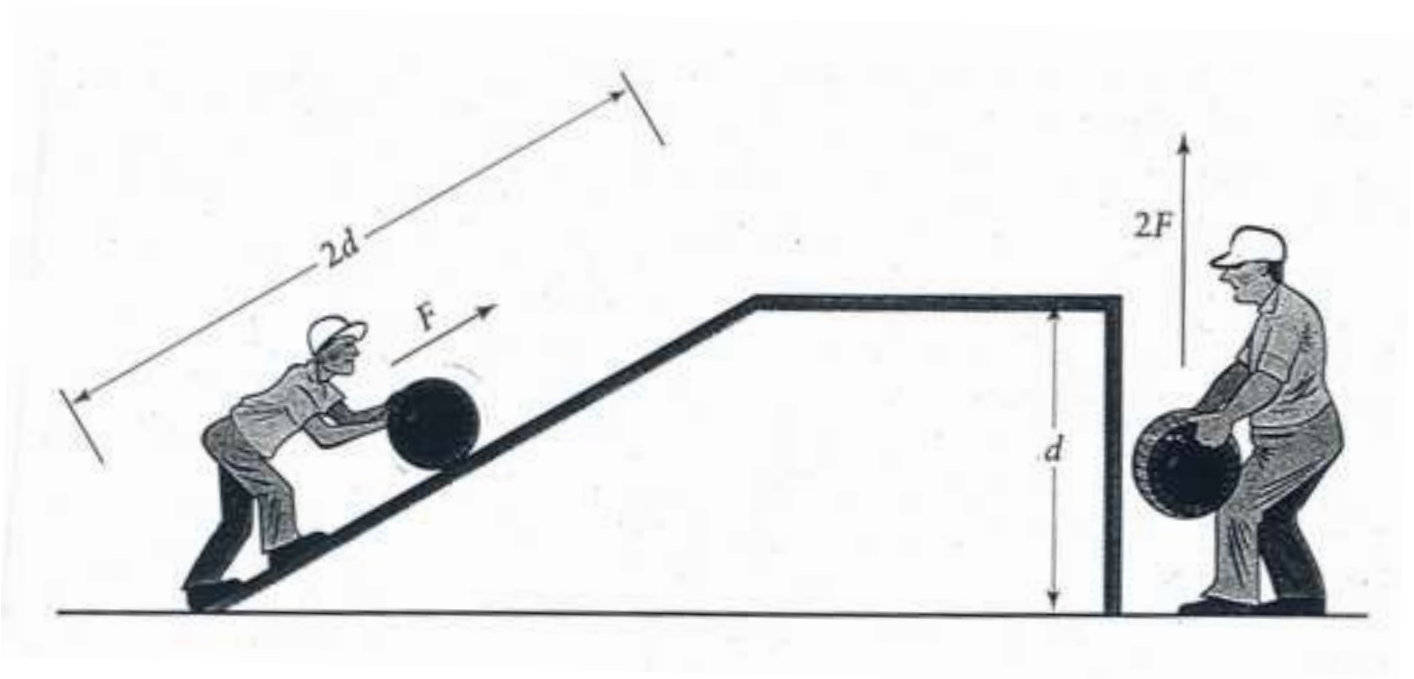
Work

Work = force $\times$ distance

Units

1 Newton meter (Nm) = 1 Joule (J)

Leverage



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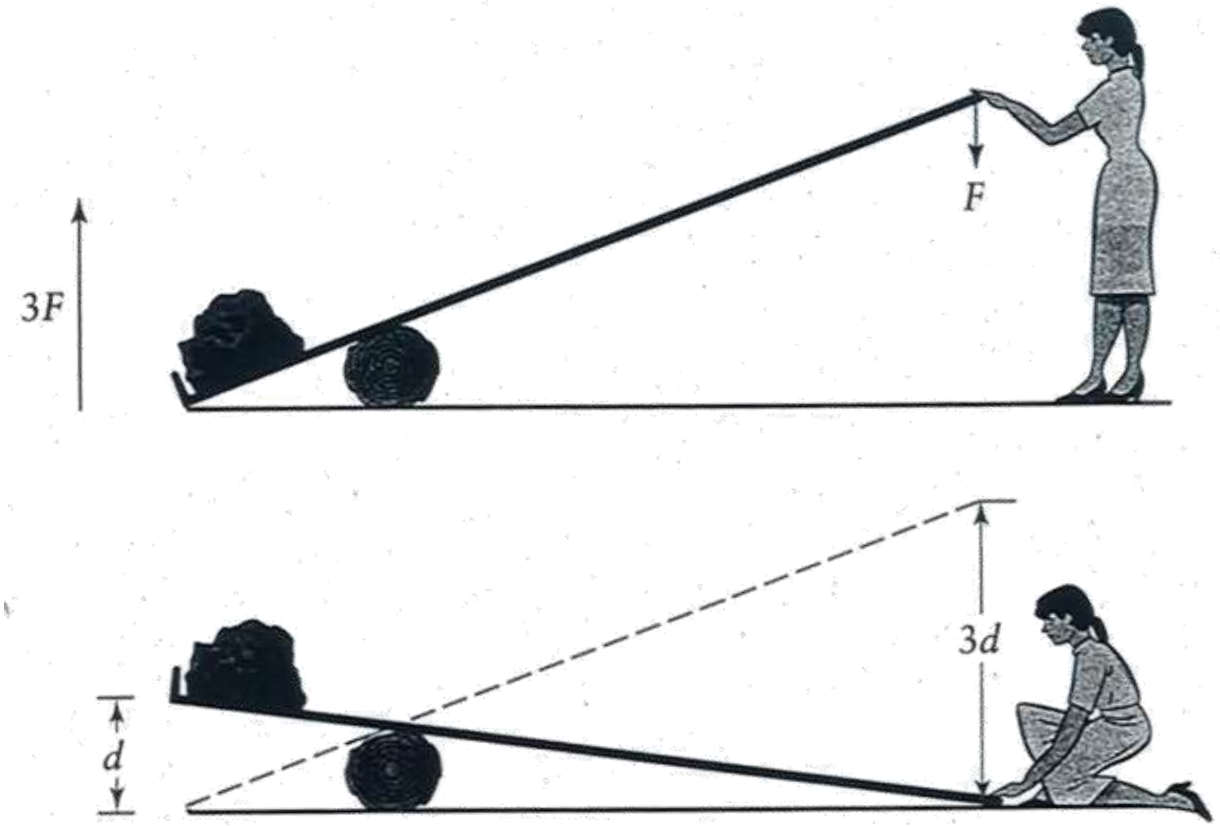
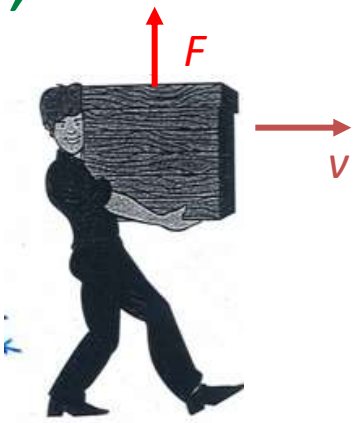


Work = force × distance

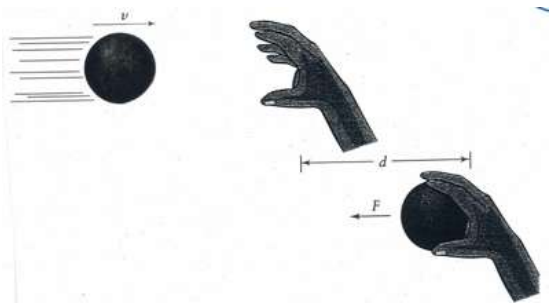
Work = force × distance

Force must be in the direction of motion

If perpendicular, no work!



If opposite, “negative work”



Energy

Amount of work an object can do

Units

Joules (J)

1 J = 1Nm

(also ft-lbs, Calories, kWh, BTU, etc.)

Clicker Question

I pick up a book from the floor and place it on a table. In the process, I have done

A. positive work on the book.
B. negative work on the book.
C. no work at all on the book.
D. imaginary work on the book.

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I pick up a book from the floor, and place it on a table. The net work done on the book in this process is

A. positive.
B. zero.
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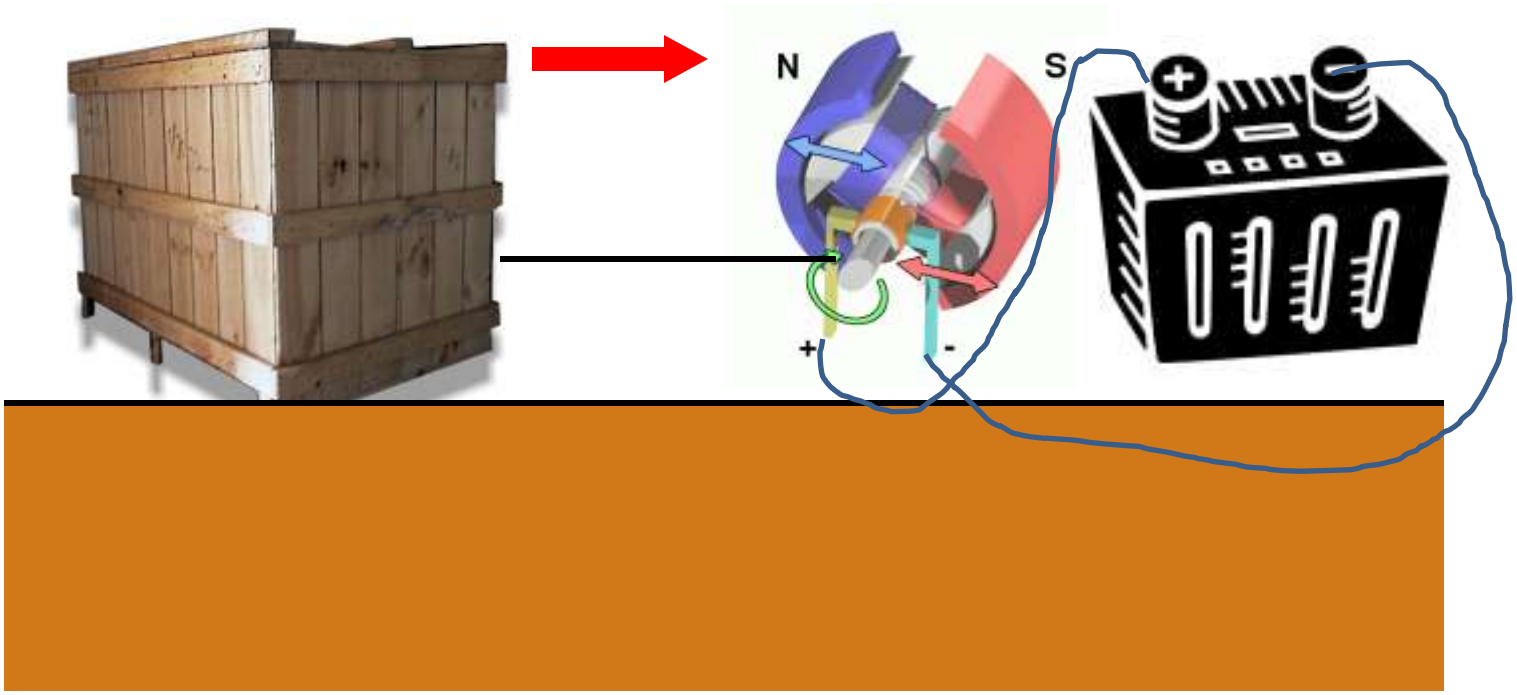
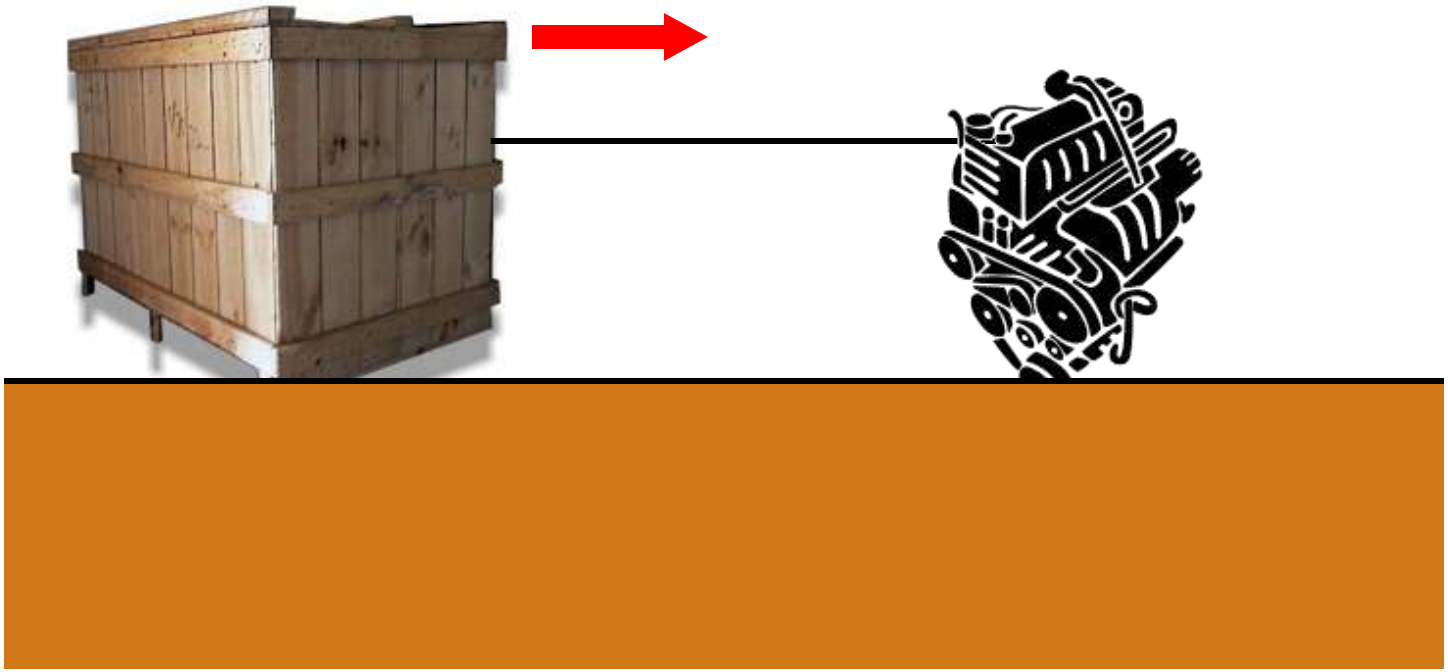
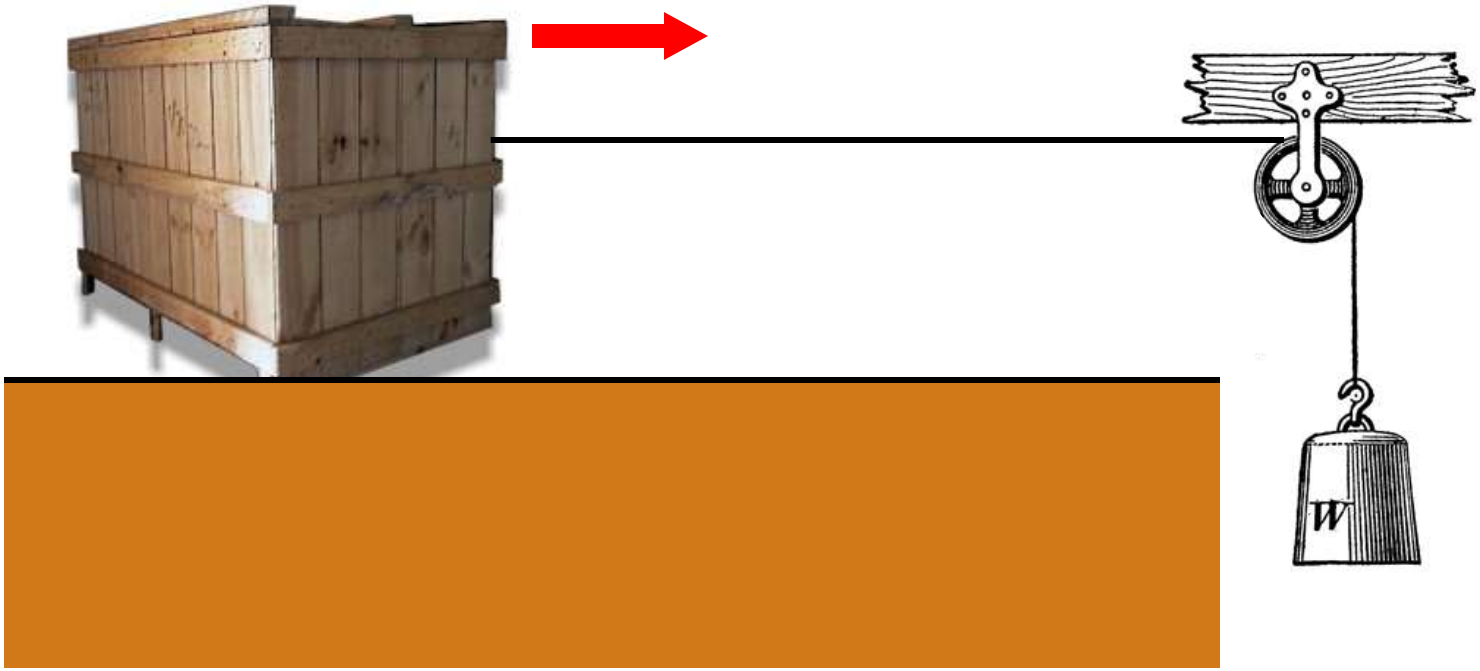
Electrical energy



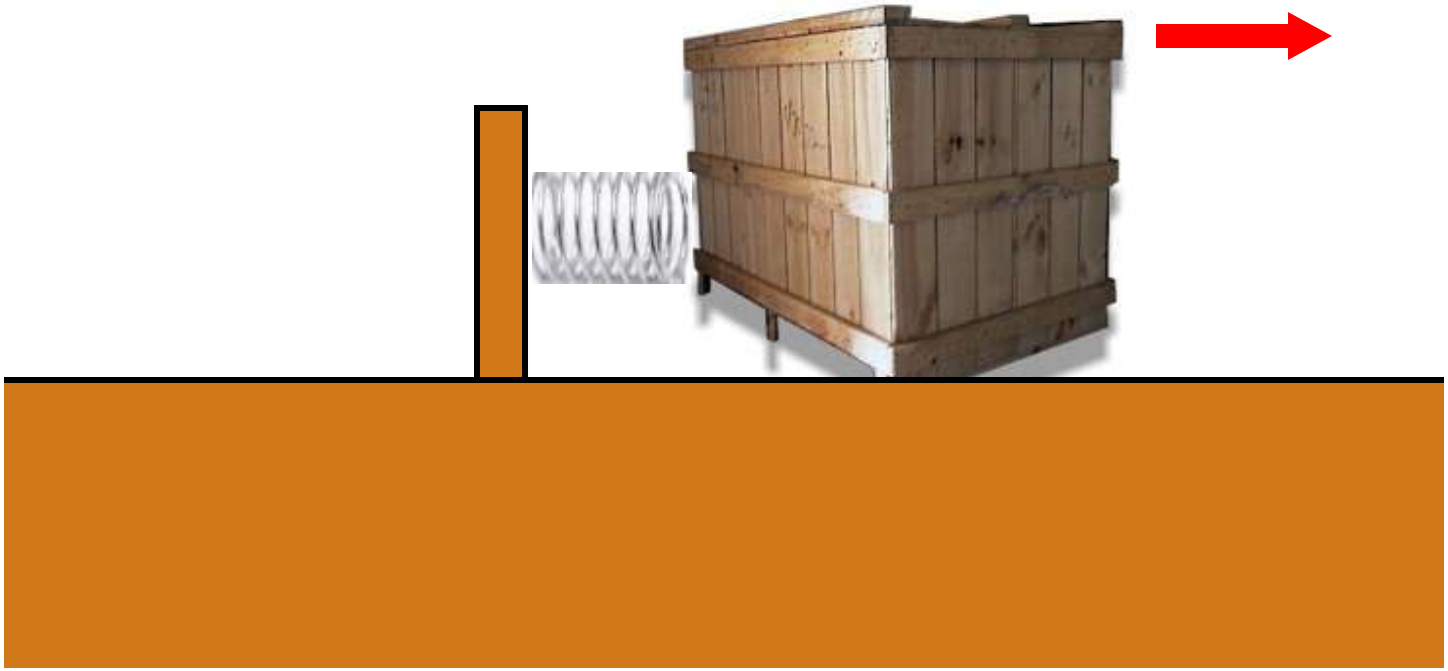
Chemical energy



Gravitational energy



Elastic energy



Kinetic energy

Types of energy

- Electric and magnetic energy
- Chemical energy
- Gravitational potential energy
- Kinetic energy
- Elastic energy
- Nuclear energy
- Radiant energy (light, etc.)
- Thermal energy

Clicker Question

The energy in a battery is stored as

A. electrical energy.
B. chemical energy.
C. kinetic energy.
D. thermal energy.
E. battery energy.

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Kinetic energy

The kinetic energy of an object in motion can be derived from Newton's laws:

$$\text{Work} = (\text{distance fallen}) \times (\text{force of gravity})$$

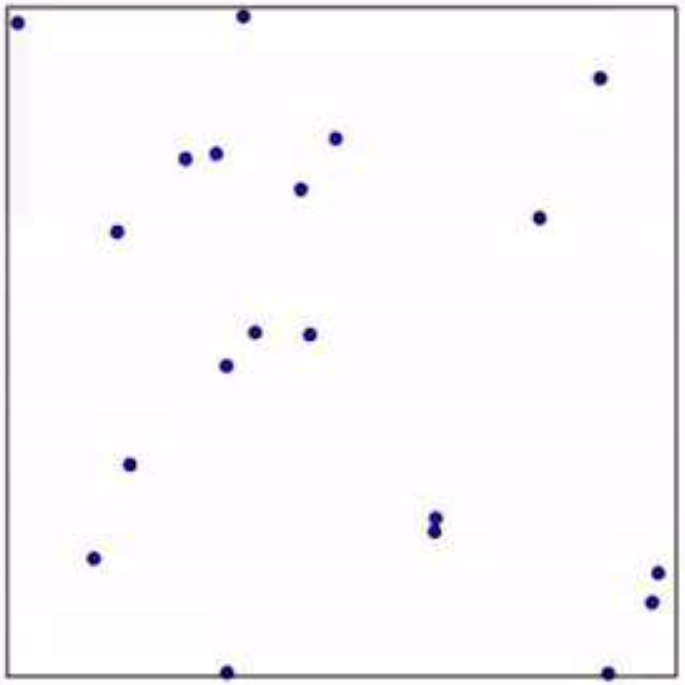
$$= (\tfrac{1}{2}\, g\, t^2) \times (m\, g)$$

$$= \tfrac{1}{2}\, m\, (g\, t)^2$$

speed after t seconds = $g\, t$

KinE = ½ × mass × the square of the speed

Thermal energy



Average kinetic energy of an atom:

$K = 3/2\ k\ T$

T = absolute temperature

k = a proportionality constant

Thermal energy

Thermal energy is a kind of “kinetic energy at the atomic scale.”

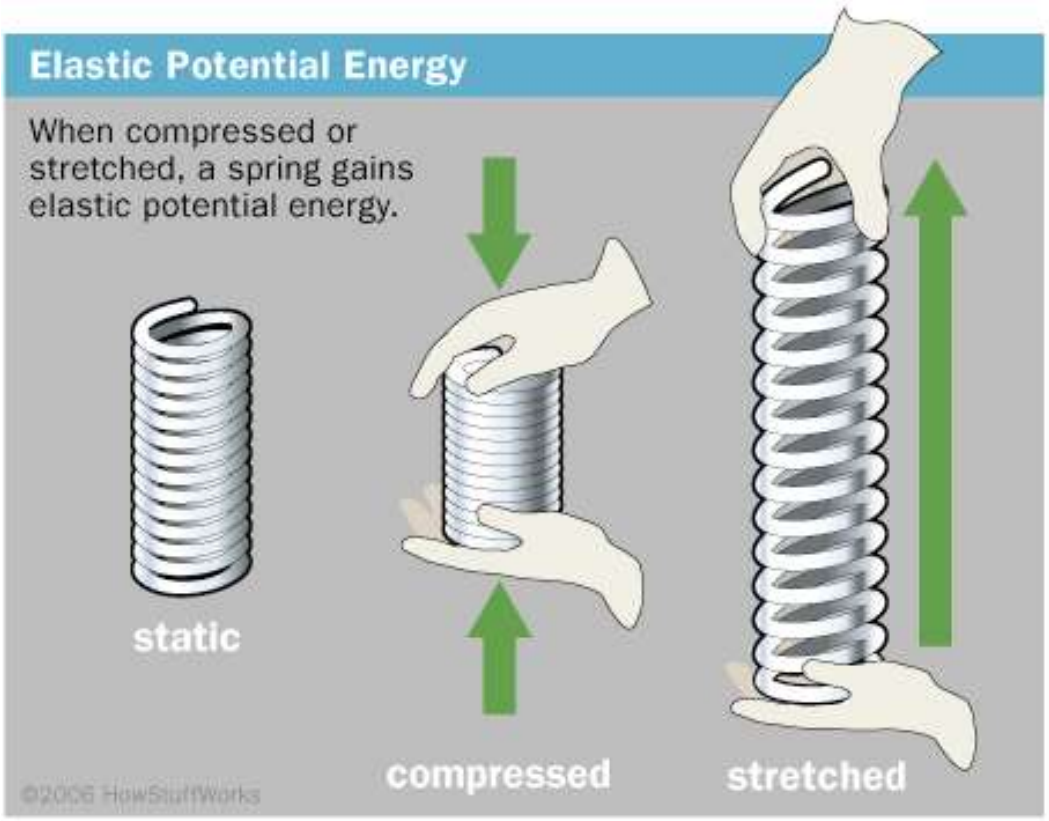
However, when we can’t see the atoms jiggling around, we call it “thermal energy,” not “kinetic energy.”

Example: I am sitting still. Do I have any kinetic energy?

Let’s demonstrate thermal energy…

Phet Simulation

Elastic energy



Hooke's law: Force $\propto$ distance stretched or compressed

Let's demonstrate this ….

Phet simulation

Chemical Energy

Clicker Question

I drop a book from a table. As it falls,

A. the force of gravity is doing zero work, and the kinetic energy increases.
B. the force of gravity is doing negative work, and the gravitational energy decreases.
C. the force of gravity is doing negative work, and the gravitational energy increases.
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