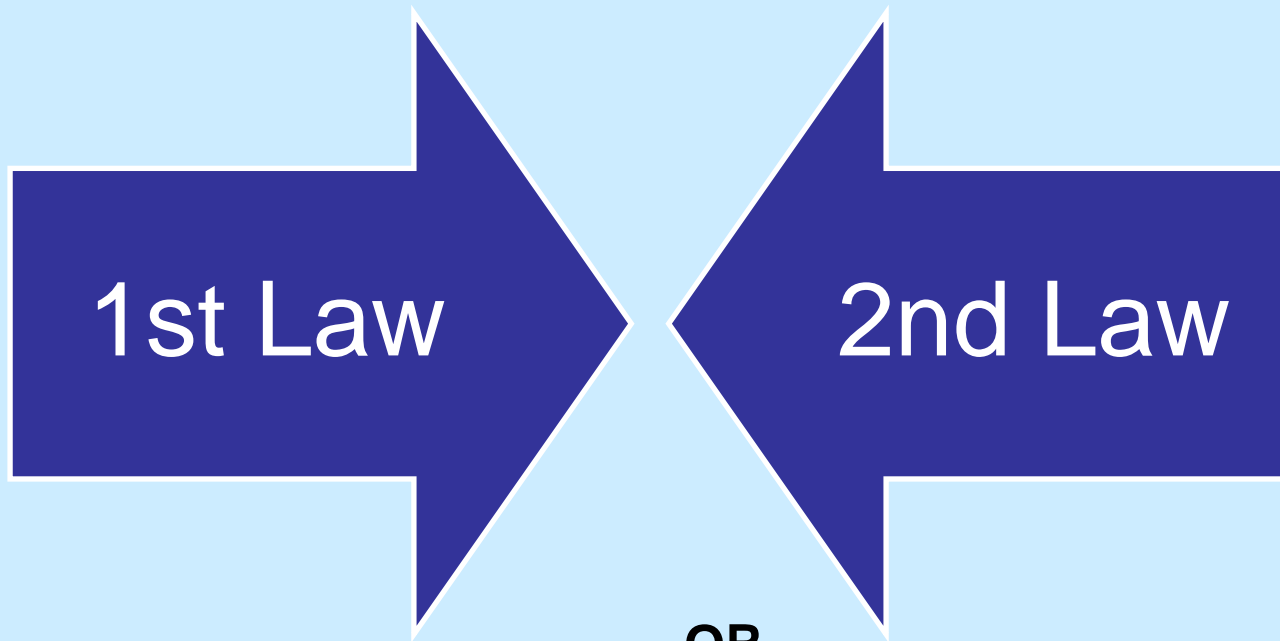


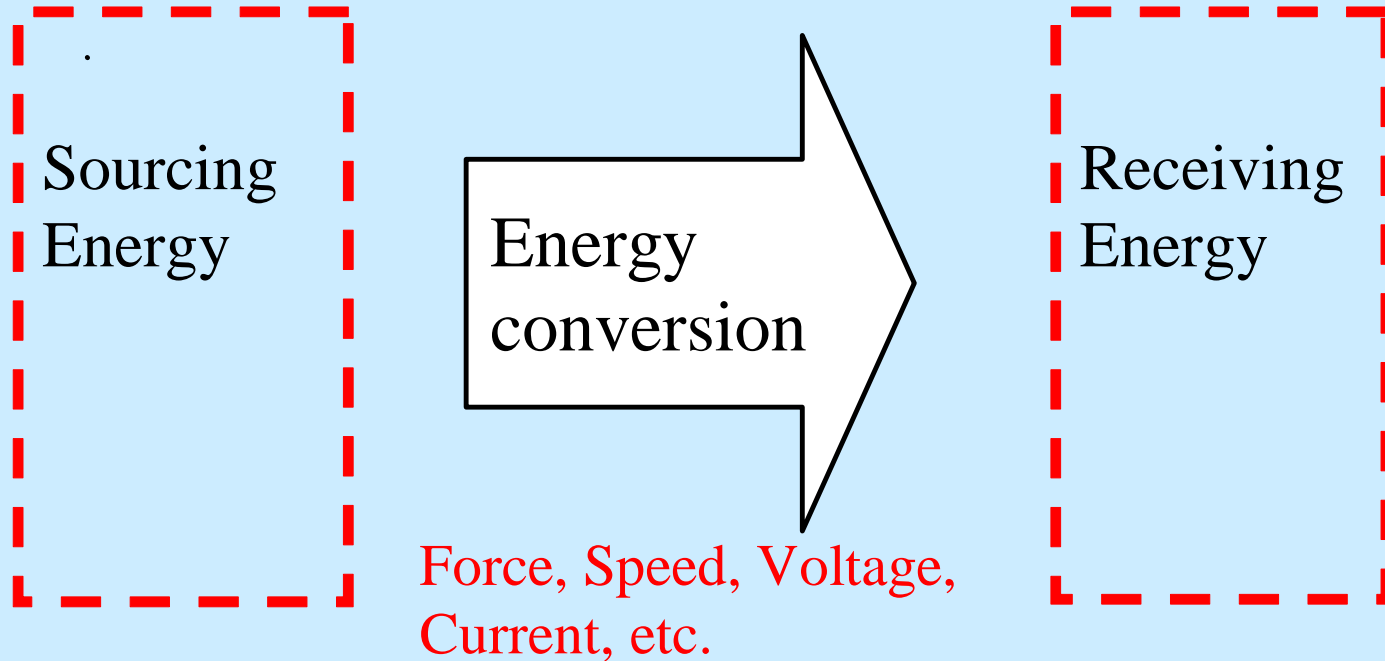
Laws of Energy



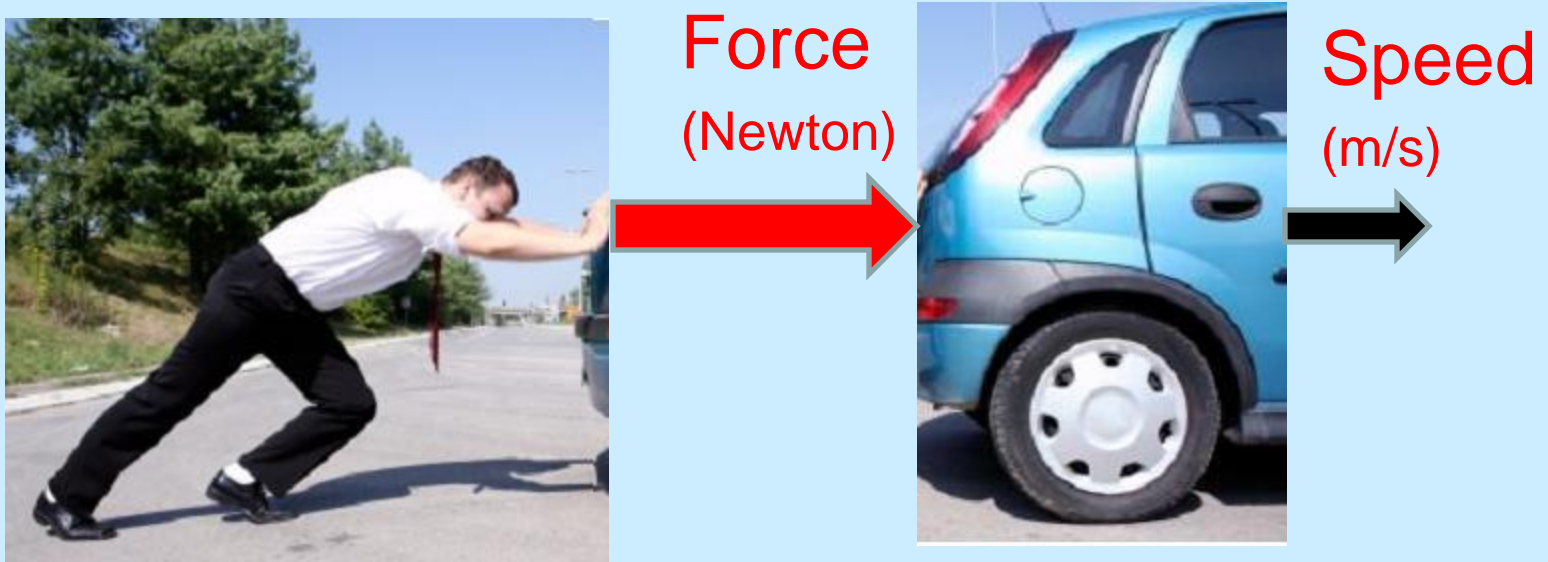
OR

What's this concern about efficiency?

Review: Power



The rate of energy transformation or transmission (i.e. power) is related to the physical quantities such as force, speed, voltage, current, etc.



For mechanical system, rate of energy transfer to an object is the product of the force (F in Newton) and the speed (S in meter/sec) in the direction of the force.

$$\text{Power} = F \times S$$

Convince Yourself

$$\text{Power} = \text{Work}/\text{Time}$$

$$\text{Work} = \text{Force} \times \text{Distance}$$

$$\text{Power} = \text{Force} \times \text{Distance}/\text{Time}$$

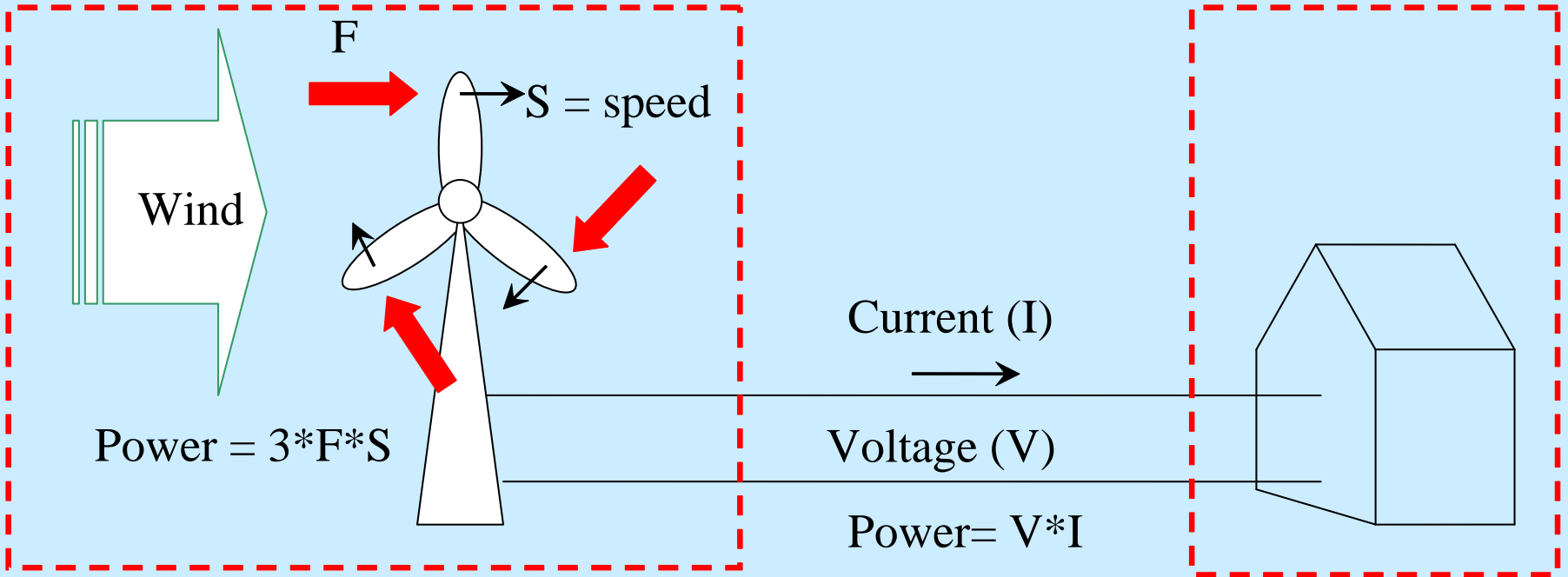
$$\text{Power} = \text{Force} \times \text{Speed} \text{ (N}\cdot\text{m/s)}$$

Clicker Question

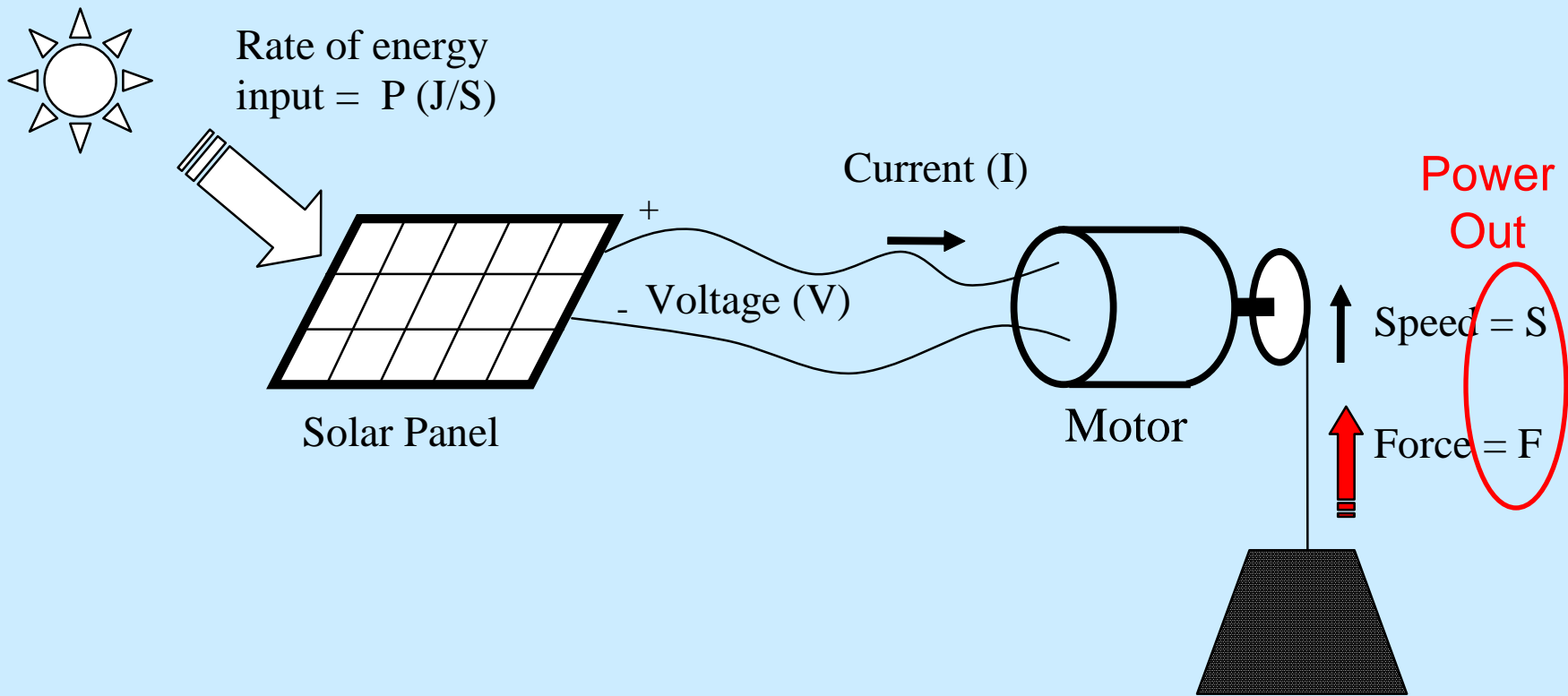
A person pushes an out-of-gas car with a force of 100 Newton (about 22.5 lb of force) to maintain a speed of 0.2 m/s. It took him 10 minutes to get to the nearest gas station.

How much **energy** did this person use to do this work? (Hint: $\text{Power} = \text{Force} \times \text{Speed}$)

- (A) 20 J
- (B) 600 J
- (C) 1200 J
- (D) 2400 J
- (E) 12000 J



If the system is 100% efficient, $\text{Power} = 3 * F * S = V * I$



Assuming solar panel's efficiency is 15% and the motor efficiency is 80%, the combined efficiency is about 12%.

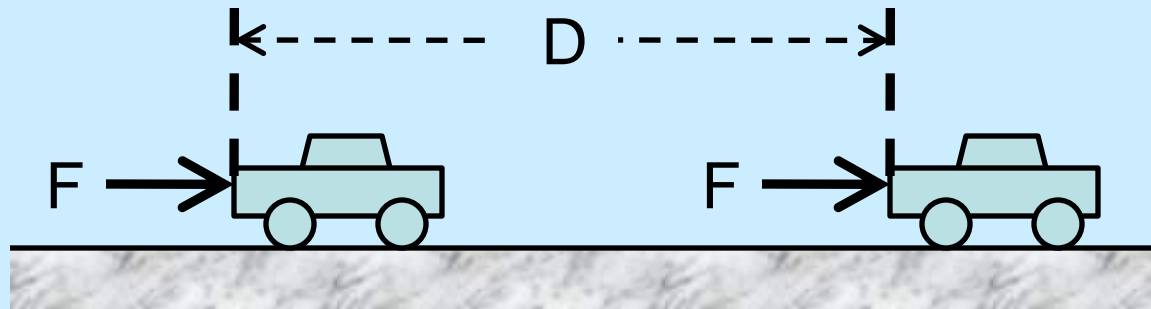
$$\text{Power Out} = F * S = 0.15 * 0.8 * P = 0.12 * P$$

If force and speed are constant, power is constant. In this case, the amount of work (or the amount of energy converted) over a period of T seconds is

$$\text{Work (J)} = \text{Power (J/s or W)} \times T \text{ (s)}$$

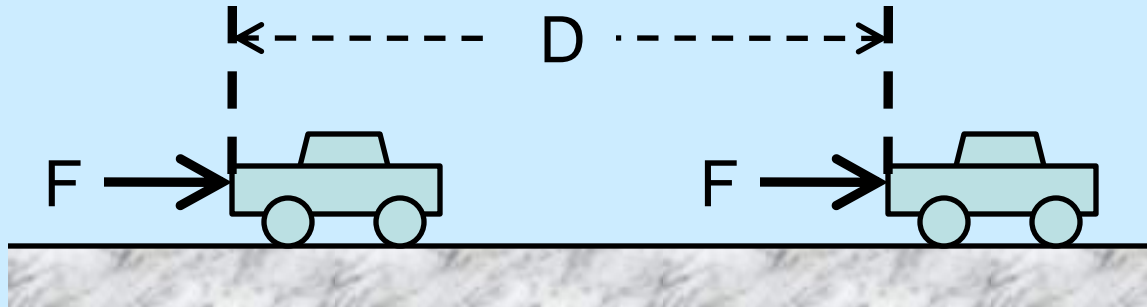
$$= \underbrace{F \text{ (N)} \times S \text{ (m/s)}}_{\text{Power}} \times T \text{ (s)}$$

$$= F(N) \times D \text{ (m)} \quad (\text{where } D \text{ is the travel distance})$$



A person pushes an out-of-gas car with a force of 100 Newton (about 22.5 lb of force) to maintain a constant speed. The nearest gas station is 120 meters away. How much Work does this person has to do to push the car to the gas station?

$$\begin{aligned}\text{Work} &= \text{Force} \times \text{Distance} \\ &= 100 \text{ (N)} \times 120 \text{ (m)} \\ &= 12000 \text{ (J)}\end{aligned}$$

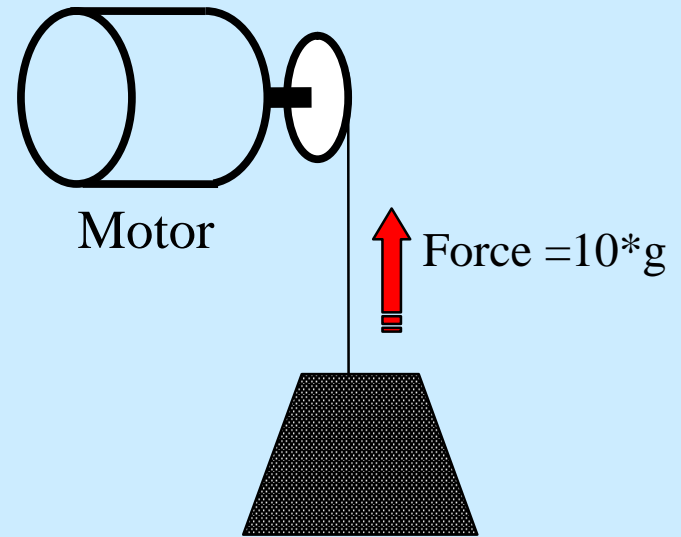


Clicker Question

How much work is done to lift a weight of 10kg by 10 meter?

Hint: Gravitational force on the weight is $F=10\text{kg} * 9.81$

- (A) 981 J
- (B) 981 W
- (C) 981 Newton
- (D) 981 Volts
- (E) 981 Amps



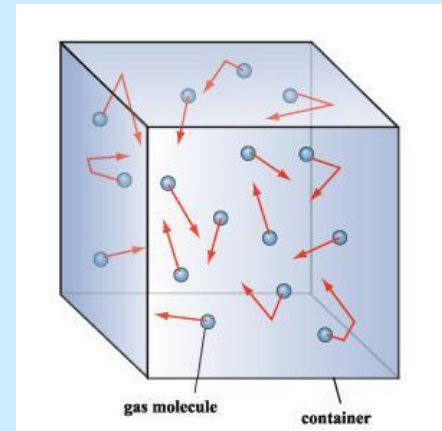
Forms of Energy

Macroscopic Energy:

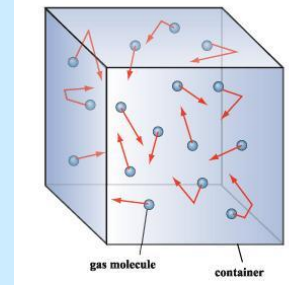
Kinetic energy, potential energy, magnetic, electric, etc.

Microscopic Energy:

- Molecular kinetic energy (particle motion at molecular and atomic level).
- Energy associated with binding forces on a molecular level, atomic level, and nucleus level. (Energy from burning fuel, atomic, and nuclear energy).



Molecular kinetic energy



- It is an “Internal Energy”.
- Due to molecular translation, vibration, rotation, electron translation & spin.
- Temperature is a measure of this energy

When heat is added to a mass, the molecular kinetic energy is increased. This energy increase can often be related to the temperature increase (ΔT) by the following equation.

$$\text{Added Energy} = \text{Increase of molecular energy} = \Delta T \times M \times C_p$$

where ΔT is in Celsius, M (mass) is in gram, and C_p is the Specific Heat constant of the material.

Some Common Specific Heat

<u>Material</u>	<u>Specific heat (J/°Cg)</u>
Air	1.01
Aluminum	0.902
Copper	0.385
Gold	0.129
Iron	0.450
Mercury	0.140
Water	4.179

Example: It takes 0.385 Joules of energy to raise 1 gram of copper 1 degree Celsius.

Example: Raising 1kg of copper 5 degree Celsius requires:

$$0.385 \times 1000 \times 5 = 1925 \text{ J}$$

Total Energy of a System

(System = One or more objects, including gas)

Total energy of a system is the sum of its macroscopic energy and microscopic energy. For simplicity, we only consider three forms of energy here:

$$\text{Total Energy} = \underbrace{\text{KE} + \text{PE}}_{\text{Macroscopic}} + \underbrace{\text{U}}_{\text{Microscopic (internal)}}$$

KE: Kinetic Energy, PE: Potential Energy

U: Molecular kinetic energy (an internal energy)

The First Law of Thermodynamics (Conservation of Energy)

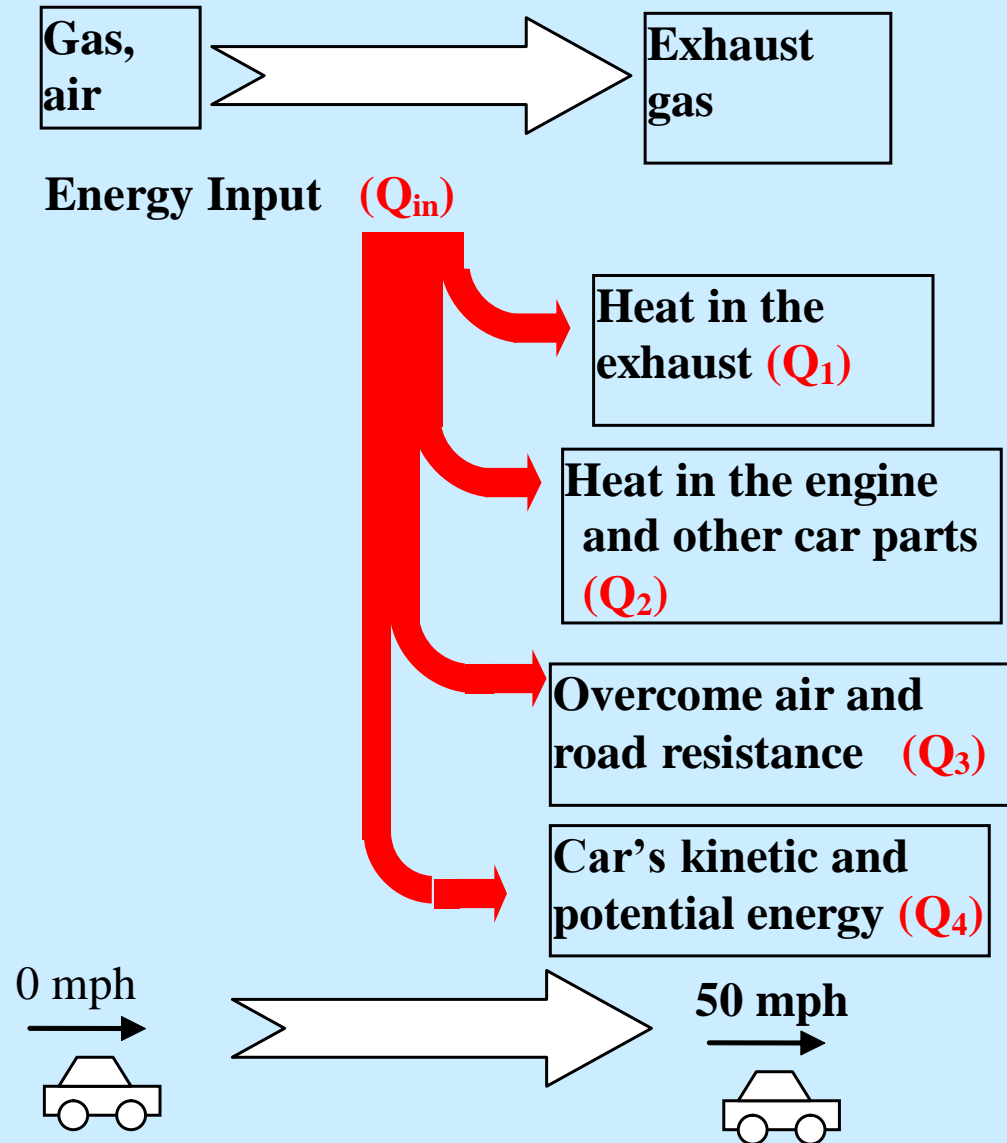
Energy cannot be destroyed or created. It only changes from one form to another form.

From 1st Law of Thermodynamics,

$$Q_{in} = Q_1 + Q_2 + Q_3 + Q_4$$

In this example, the **efficiency** of the system is

$$\text{Efficiency} = \frac{Q_4}{Q_{in}}$$



The First Law of Thermodynamics (Conservation of Energy)

From the 1st law of Thermodynamics, for a system

Energy In – Energy Out = The system's total energy change

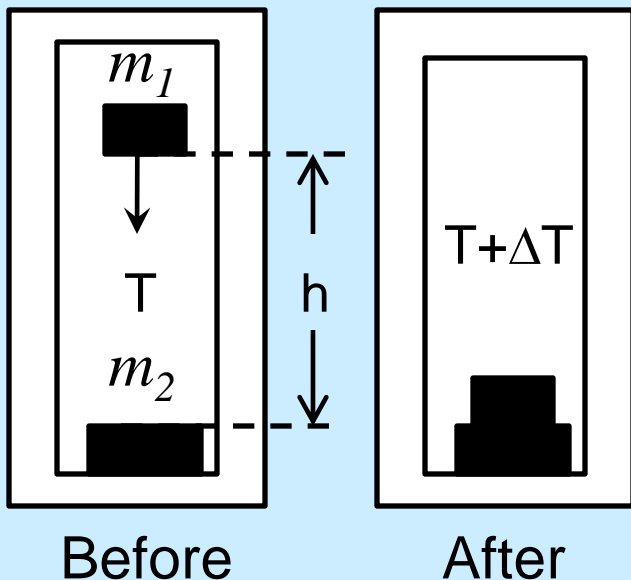
(Recall that Total Energy = KE + PE + U)

Example: In a well insulated chamber, a steel block of mass m_1 is dropped on a steel plate of mass m_2 . Find the temperature change of the masses, if any.

Answer: This system does not have input or output energy and therefore the system's total energy remains the same.

Before: Total Energy = $KE + PE + U$; (Potential + Internal)

After: Total Energy = $KE + PE + U + \Delta U$; (Internal + change)



Since total energy is unchanged,

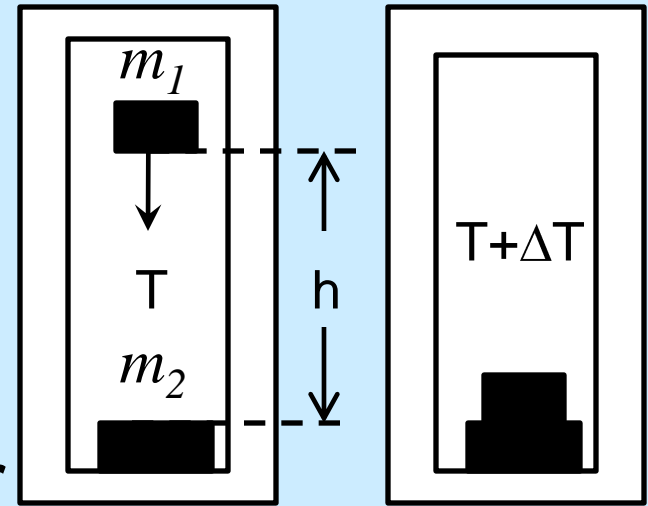
$$PE = \Delta U$$

Solve the following equation for ΔT .

$$m_1 gh = \Delta T (m_1 + m_2) C_p$$

Group Problem

- Form group of 2 or 3
- put name and SID on paper

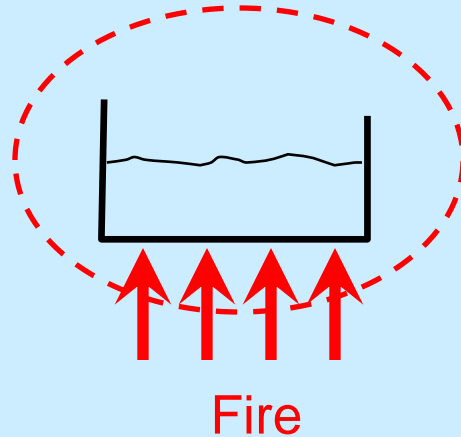


Block A, a 10kg block of aluminum is suspended 2 meters directly above an identical block, Block B. These two blocks are both in a thermally insulated enclosure in which air is completely evacuated. If the temperature of both blocks is initially 25 C, what is the temperature of the blocks after the Block A is dropped on Block B below it?

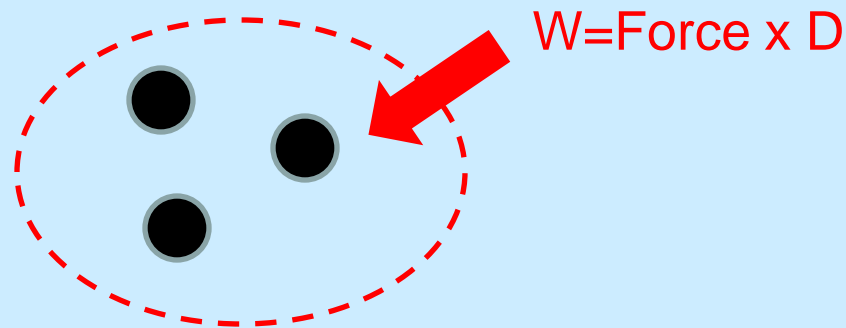
Aluminum 0.902J/Cg

Energy in or out of a system can be in the form of

1. Heat transfer: Heat the system up (in) or cool it down (out)



2. Mechanical work: Apply force to the system and cause a motion i.e. $W=F \cdot D$ (energy-in) or the system applies a force to an external object and causes motion (energy-out)

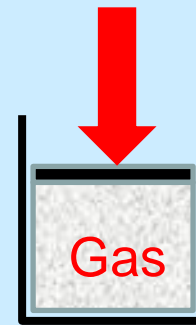


The 1st law of Thermodynamics

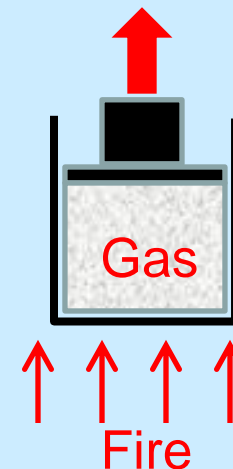
$$\text{Energy In} - \text{Energy Out} = \text{Total Energy Change}$$

- When a volume of gas is compressed in a cylinder (energy-in) the gas temperature is increased (energy change) by an amount that is proportional to the work done W .
- When the gas in a cylinder is heated up by fire. The energy from the heat (energy-in) results in (1) increase gas temperature (energy change) and (2) mechanical work done by the piston. (energy out)

$$W = \text{Force} \times D$$



$$W = \text{Force} \times D$$



Efficiency < 1

- Since the first law of thermodynamics says the energy output cannot exceed the energy input (energy is conserved)

$$\text{Efficiency} = \frac{\text{Output energy}}{\text{Input energy}} \leq 1$$

Clicker Question

When a volume of gas is compressed,

- (A) Its temperature goes up.
- (B) Its temperature goes down.
- (C) Its internal energy remains unchanged.
- (D) Work is performed by the gas

The Second Law of Thermodynamics

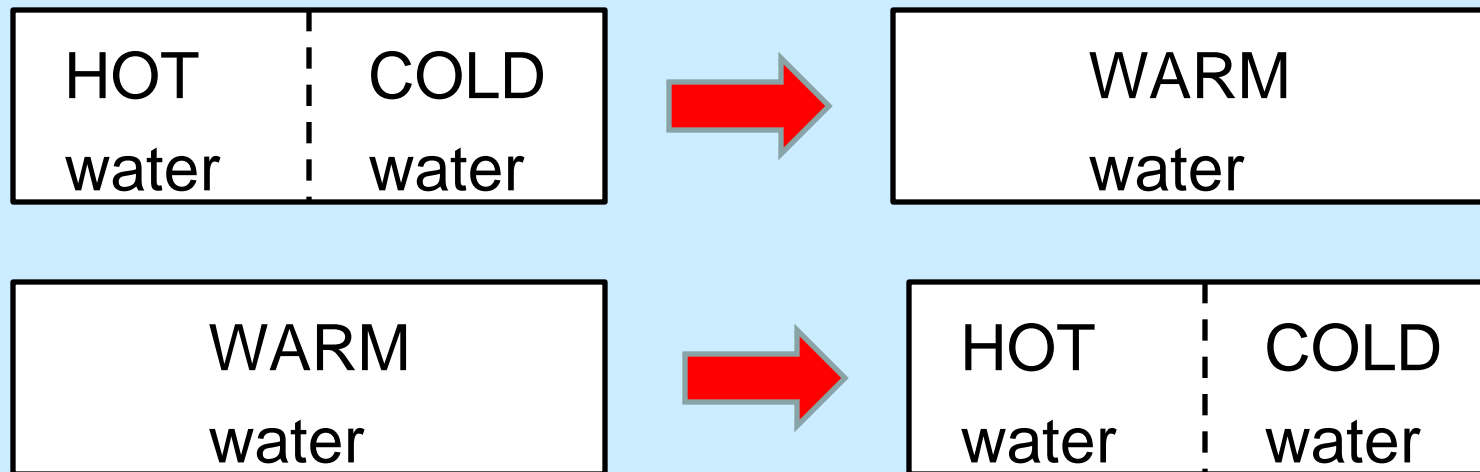
Expression of the tendency that over time, differences in temperature, pressure, and chemical potential equilibrate in an isolated system.

(Wikipedia)

The second law tells us that energy transformation processes in an isolated system must occur in a certain direction. **For example, heat travels from hot to cold.**

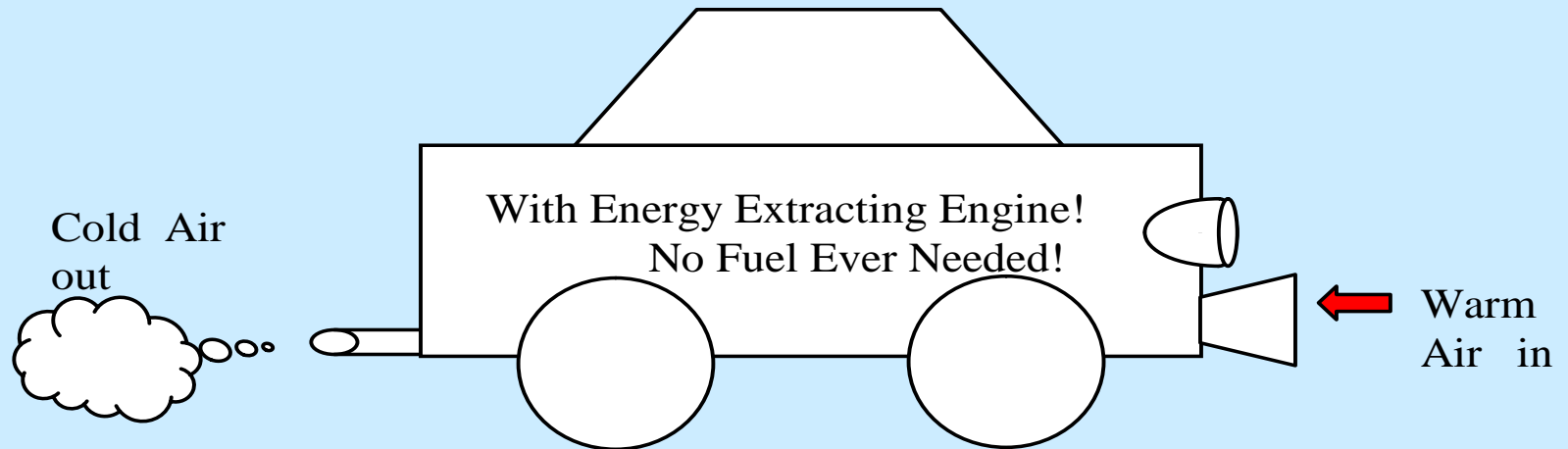
A Point to think about

If a behavior does not violate any physical law, it is possible. Neither one of the following behaviors violates the First Law of Thermodynamics since the total energy is the same before and after the process.



The 2nd behavior is not possible for an isolated system.

Is it possible to build a car that runs entirely on the energy extracted from the ambient air?



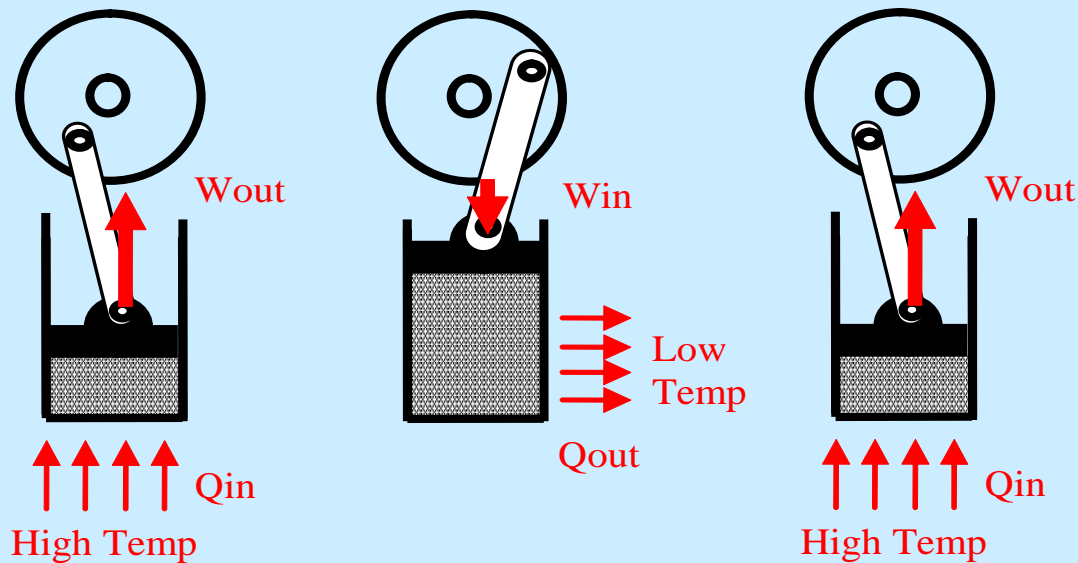
This is impossible according to the Second Law of Thermodynamics. You will learn more about this in your future physics and engineering classes!

When a volume of gas is compressed, its temperature goes up. This is true because which of the following physic law

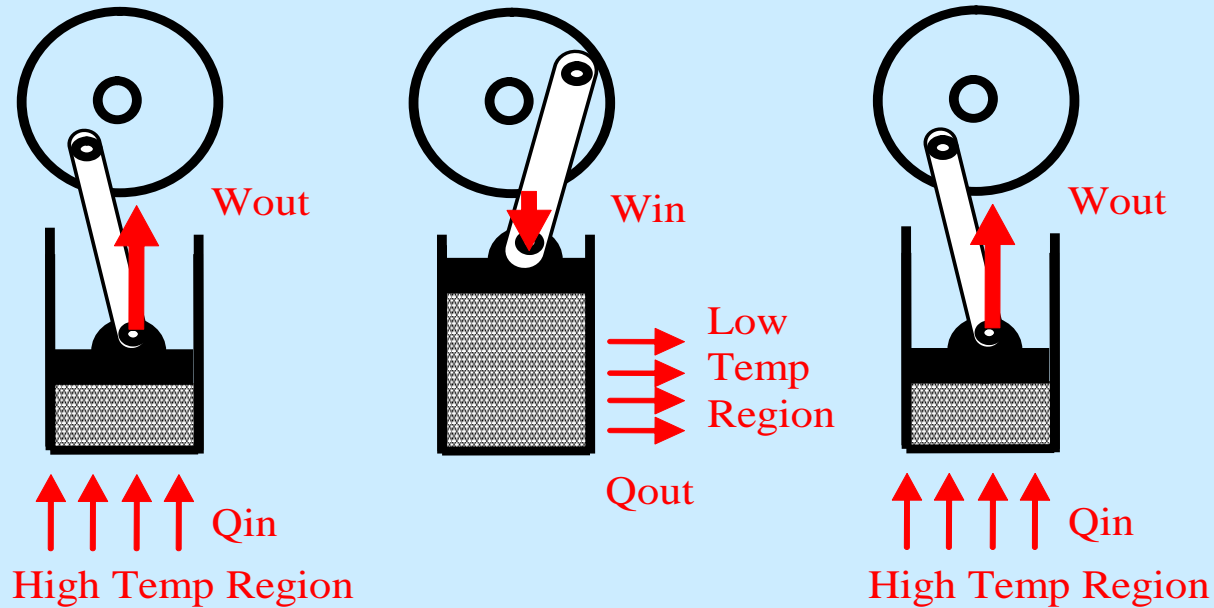
- (A) Newton's Law
- (B) Ohm's Law
- (C) First Law of Thermodynamics
- (D) Second Law of Thermodynamics

Heat Engine (example: car engine)

It is possible to design a machine that takes the energy from a heat source and transforms it to mechanical work. Such machine is called "Heat Engine". The theory of operation of this machine cannot violate the laws of thermodynamics, of course.



W_{out} is the work performed by the gas and W_{in} is the work performed to the gas due to, for example, the rotational kinetic energy of the wheel. For the engine to do work, we need $W_{out} > W_{in}$.



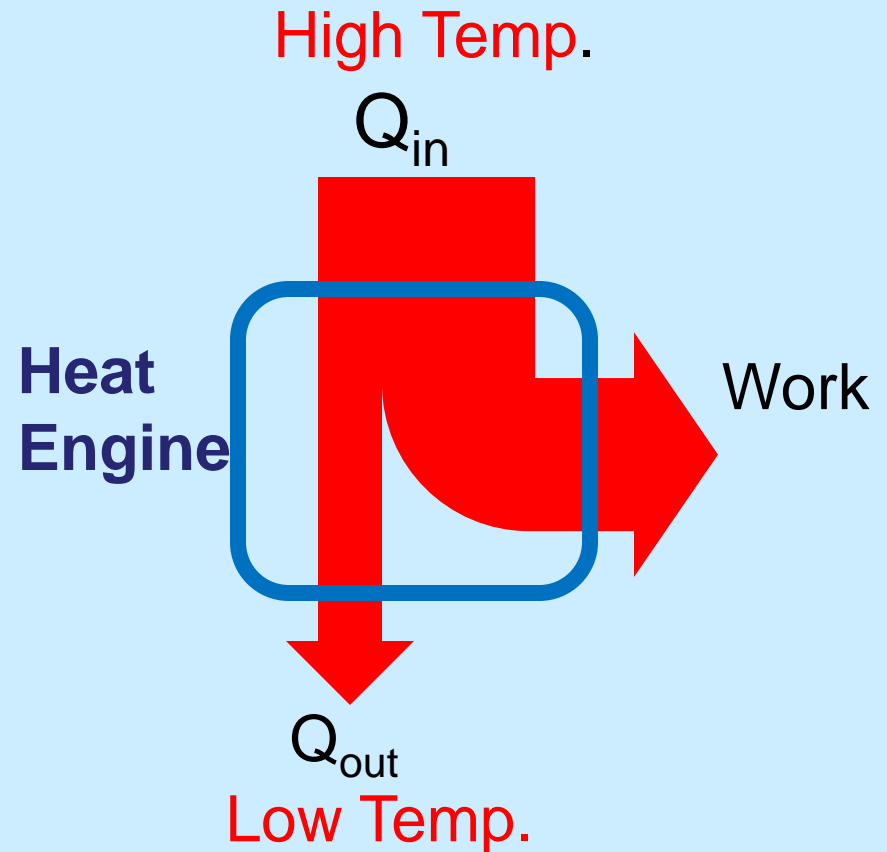
$$\begin{aligned} \text{Best Theoretical Efficiency} &= \frac{\text{Mechanical work out}}{\text{Total Heat Energy in}} \\ &= 1 - \frac{\text{Temperature of the cold side}}{\text{Temperature of the hot side}} \end{aligned}$$

Note that higher efficiency can be obtained with higher temperature difference between the hot side and the cold side.

Heat Flow Diagram

Heat Engine needs a high temperature (energy source) and a low temperature (energy sink).

Mechanical work is performed as heat flowing from the high temperature side to the low temperature side.



Which one of the following statement best describes the **Second Law of Thermodynamics**

- (A) Energy cannot be created or destroyed.
- (B) Some form of energy is more useful than others.
- (C) There is no free energy.
- (D) Efficiency of any system cannot be greater than 1.

For a heat engine to work, which of the following item is required?

- A. Piston, spark plug, and cylinder
- B. Electric current and voltage
- C. High temperature source and low temperature sink
- D. Oil and gas
- E. Fuel and combustion