Energy Science and Engineering

Unit-I Energy and its Usage: Units and scales of energy use, Mechanical energy and transport, Heat energy: Conversion between heat and mechanical energy, Electromagnetic energy: Storage, conversion, transmission and radiation, Introduction to the quantum, energy quantization, Energy in chemical systems and processes, flow of CO_2, Entropy and temperature, carnot and Stirling heat engines, Phase change energy conversion, refrigeration and heat pumps, Internal combustion engines, Steam and gas power cycles, the physics of power plants. Solid-state phenomena including photo, thermal and electrical aspects

Electricity Companies in India 2021

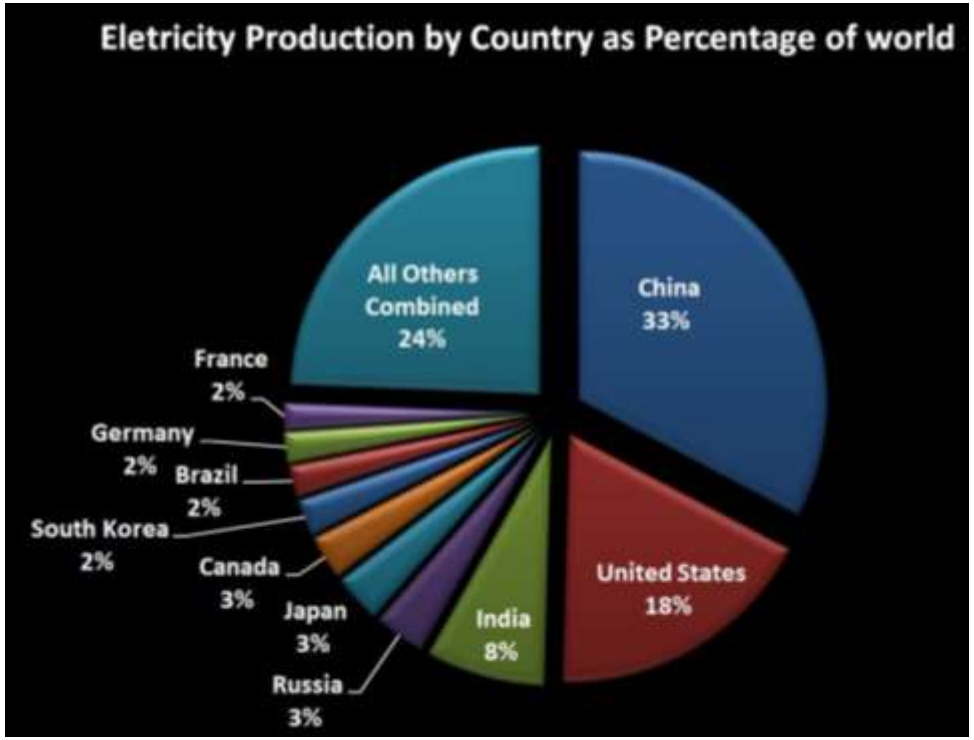
According to the Central Electricity Authority, the total installed power generation capacity of the country stood at 3,56,818 MW in May 2019. This included 2,26,279 MW of thermal power generation capacity, 45,399 MW of hydropower generation, and 78,359 MW of renewable energy generation capacity.

Top Electricity Companies in India

1. NTPC Ltd
2. Tata Power Company Ltd
3. Adani Power Limited
4. Torrent Power Ltd
5. JSW Energy Ltd
6. SJVN Ltd
7. Adani Green Energy Ltd

Production [edit]

Rank	Country/region	Electricity production (GWh)	Date of information
N/A	*World total*	27,644,800	2019[1]
1	China	7,503,400	2019[2]
2	United States	4,401,300	2019[2]
3	India	1,558,700	2019[2]
4	Russia	1,118,100	2019[2]
5	Japan	1,036,300	2019[2]
6	Canada	954,400	2018[1]
7	South Korea	794,300	2018[1]
8	Brazil	688,000	2018[1]
9	Germany	648,700	2018[1]
10	France	574,200	2018[1]



- **All India Installed Capacity (MW)**

As on 31.10.2016 (In MW)

Sector	Thermal	Nuclear	Hydro	Renewable	Grand Total	Sector wise %
Central	58,751	5,780	11,651	-	76,182	25%
State	71,155		28,341	1,975	1,01,471	33%
Private	82,563		3,120	43,942	1,29,625	42%
All India	2,12,469	5,780	43,112	45,917	3,07,278	
Discipline wise %	69%	2%	14%	15%		

In MW

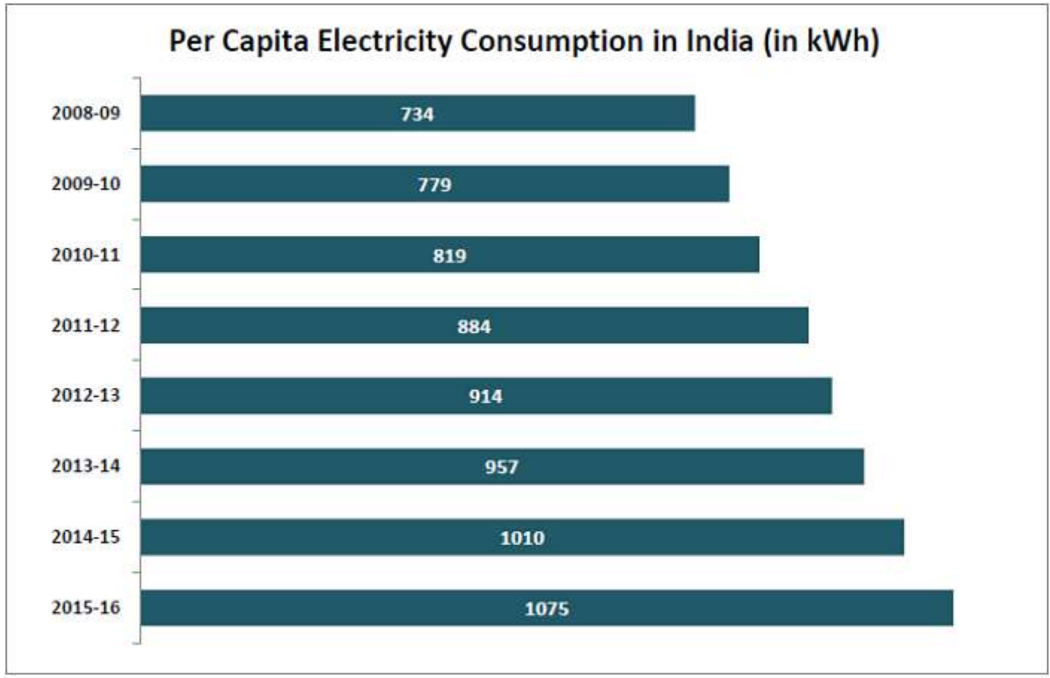
- **Summary of Capacity Addition Targets for XII Plan**

	Thermal	Nuclear	Hydro	Total	Sector wise %
Central	14,878	5,300	6,004	**26,182**	**30%**
State	13,922	-	1,608	**15,530**	**18%**
Private	43,540	-	3,285	**46,825**	**52%**
Total	**72,340**	**5,300**	**10,897**	**88,537**	
Discipline wise %	**82%**	**6%**	**12%**		

- Per capita power consumption at 1075 kWh - Low as compared to world average (2015-16)
- Present Peak shortage – 3.20% (2015-16)
- Present Energy shortage – 2.10% (2015-16)

Increase in demand of power due to following factors

- Rural Electrification
- GDP Growth Rate
- 24x7 Power for All



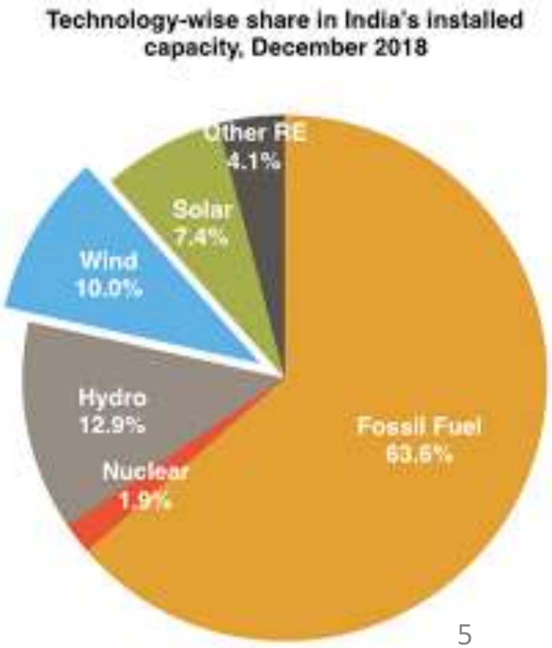
Push to Renewables

Target by 2022 : 100 GW of solar and 60 GW of wind energy

•Solar projects 20,900 MW tendered

•Green Energy Corridors of $ 5.6 billion envisaged for transmission of renewable energy

•33 Solar parks in 20 states are envisaged



<u>24X7 Power For All (PFA) by 2019</u> - Uninterrupted power supply 24X7

A comprehensive programme encompasses overall development of power sector including reforms at all India level

•Envisages building generation, transmission and distribution capacities

•Operational efficiency & reform measures

WHICH COUNTRIES LED THE WAY IN 2019?

Annual Investment / Net Capacity Additions / Production in 2019

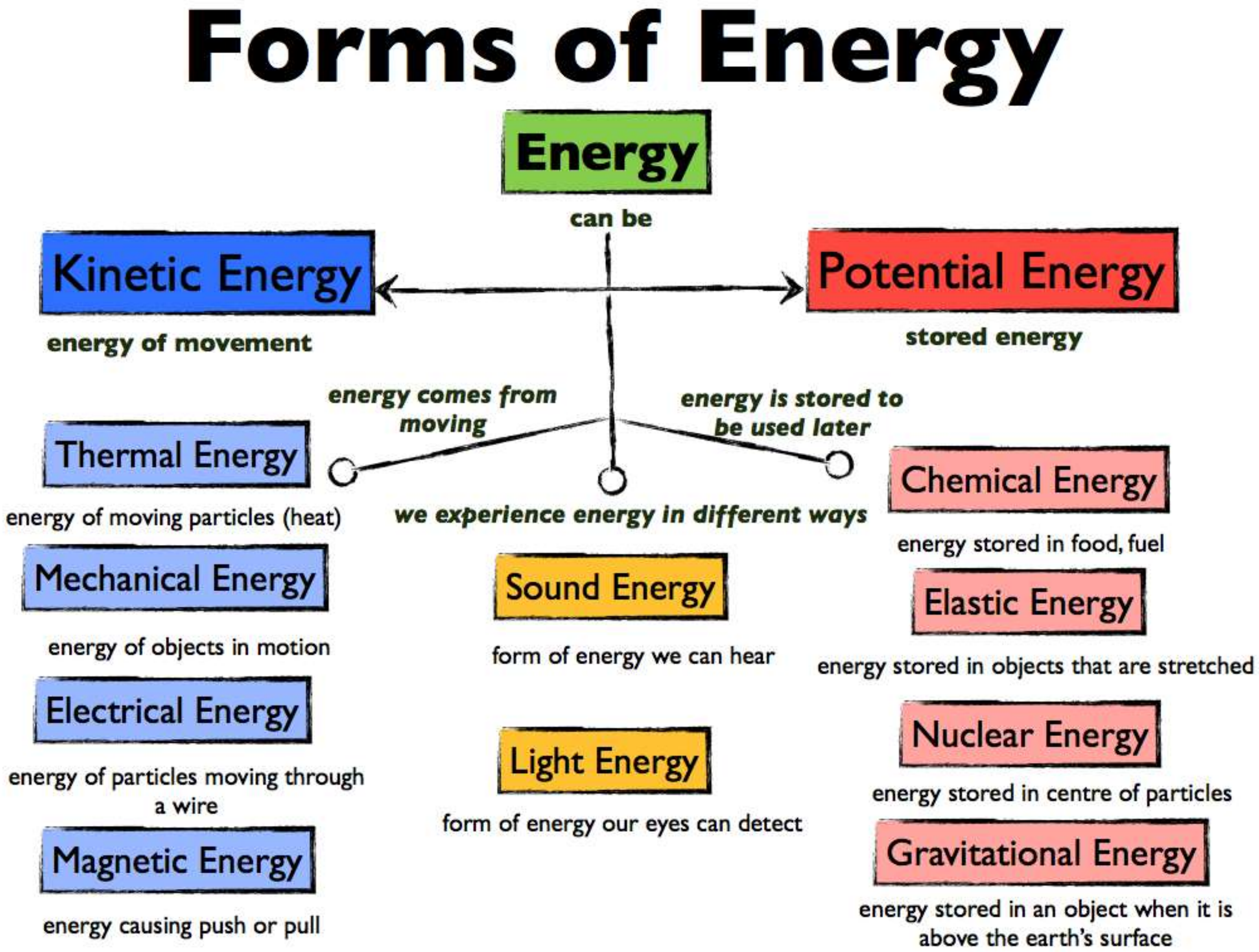
Technologies ordered based on total capacity additions in 2019.

	1	2	3	4	5
Investment in renewable power and fuels capacity (not including hydropower over 50 MW)	**China**	United States	Japan	India	Chinese Taipei
Solar PV capacity	**China**	United States	India	Japan	Vietnam
Wind power capacity	**China**	United States	United Kingdom	India	Spain
Hydropower capacity	**Brazil**	China	Lao PDR	Bhutan	Tajikistan
Geothermal power capacity	**Turkey**	Indonesia	Kenya	Costa Rica	Japan
Concentrating solar thermal power (CSP) capacity	**Israel**	China	South Africa	Kuwait	France
Solar water heating capacity	**China**	Turkey	India	Brazil	United States
Ethanol production	**United States**	Brazil	China	India	Canada
Biodiesel production	**Indonesia**	United States	Brazil	Germany	France

As in past years, **China** led many key annual categories for renewable energy in 2019.

Energy the capacity for doing work.

It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms. There are, moreover, heat and work—i.e., energy in the process of transfer from one body to another. After it has been transferred, energy is always designated according to its nature. Hence, heat transferred may become thermal energy, while work done may manifest itself in the form of mechanical energy.



SI units for energy

- The SI unit of energy is a Joule: 1 kg*m²/s² = 1 Newton*m (Newton is the unit of Force)
  - mass * velocity ²
  - mass * g * height (on earth, g = 9.81 m/s²)
  - for an ideal gas = $c_v k_B T$ (c_v =3/2 for a monatomic gas)
- Power is energy per time: 1 Watt = 1 Joule/s = 1 kg*m²/s³
  - most commonly used in electricity, but also for vehicles in horsepower (acceleration time)

	System of Units		
	SI	Metric	English
Energy and Exergy	Joule (J)	kcal	Btu
Work	N×m= J	kg_f×m	lb_f×ft
Heat[a]	cal	kcal (1000 cal)	Btu
Power	J/s = W (Watt)	KWh	hp

[a] Heat needed to warm by one degree of temperature a unit of mass of water (cal: 1 gram, 1°C; kcal: 1kg, 1°C; Btu: 1lb, 1°F).

Source: Based on Kostic (2004, p. 529) and Levenspiel (1997, p. 6).

Other common energy units

http://www.onlineconversion.com/energy.htm

Energy conversion			
Unit	Quantity	to	Note
1 calorie =	4.1868000	Joule	
1 kiloWatt hour = kWh =	3600000	Joule	A power of 1 kW for a duration of 1 hour.
1 British Thermal Unit = btu	1055.06	Joule	It is a is a unit of energy used in North America.
1 ton oil equivalent = 1 toe	4.19E+010	Joule	It is the rounded-off amount of energy that would be produced by burning one metric ton of crude oil.
1 ton coal equivalent	2.93E+10	Joule	
1 ton oil equivalent = 1 toe	1 / 7.33	Barrel of oil	or 1 / 7.1 or 1 / 7.4 ...
1 cubic meter of natural gas	3.70E+07	Joule	or roughly 1000 btu/ft3
1000 Watts for one year	3.16E+010	Joule	for the 2000 Watt society
1000 Watts for one year	8.77E+006	kWh	for the 2000 Watt society
1 horsepower	7.46E+002	Watts	

Mechanical Energy Transfers

Any time a force causes energy to go from one store into another, it is a mechanical energy transfer. A mechanical energy transfer takes place when work is done by a force over a displacement (parallel with that force).

	
When an object falls energy is **transferred by gravity** from the Gravitational Potential Energy Store of the object to the Kinetic Energy Store of the object.	The front brakes of this car are glowing from the high temperature. Energy has been **transferred by friction** from the Kinetic Energy Store of the car to the Thermal Energy Store of the brakes.

Any object that possesses mechanical energy - whether it is in the form of potential energy or kinetic energy - is able to do work. That is, its mechanical energy enables that object to apply a force to another object in order to cause it to be displaced.

Heat is a form of energy that transfers from the higher temperature object to the lower temperature object, and is transferred through the conduction, the convection and the radiation.

Temperature is the degree of hotness or coldness of a body.

Thermal energy refers to the energy contained within a system that is responsible for its temperature.

Temperature vs. Thermal Energy

<u>temperature</u> —**average** kinetic energy (energy of motion) or **average speed** of all the particles in a material

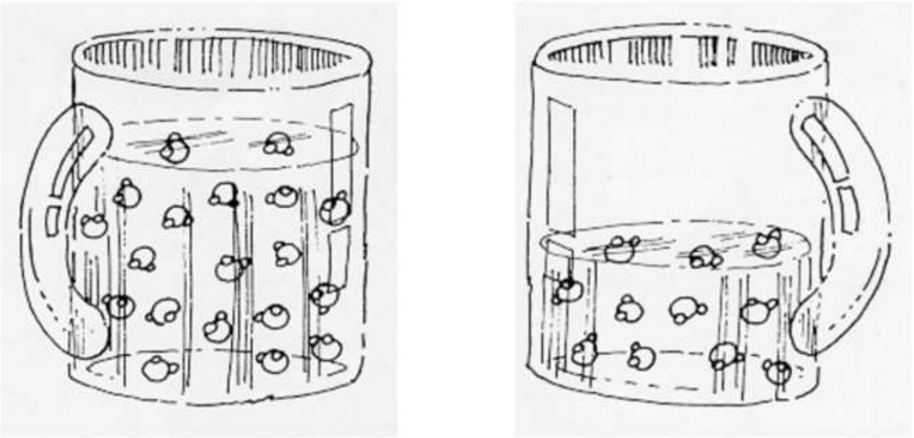
a. higher temp. = particles move faster and farther apart
b. lower temp. = particles move slower and closer together

<u>thermal energy</u>—total kinetic energy of all the particles in a material

<u>heat</u>—energy transferred between two objects of **different temperature**

more molecules = more thermal energy

95°C 100°C



← heat transfer

more thermal energy less thermal energy

The importance of the heat

- The heat is very important in our daily life in warming the house, cooking, heating the water and drying the washed clothes.

- The heat has many usages in the industry as making and processing the food and manufacture of the glass, the paper, the textile, ………etc.

- The steam has a high specific heat (more than the water), It is used to carry a lot of heat energy at high pressures to run the rail engines or the rotors in AC generators.

Heat is transported in 3 primary ways:

Conduction: Heat transfer between adjacent molecules.

Ex. Metal spoon in cup of hot coffee

Convection: Heat transfer through flow of liquid/gas

Ex. Air rising over hot blacktop parking lot

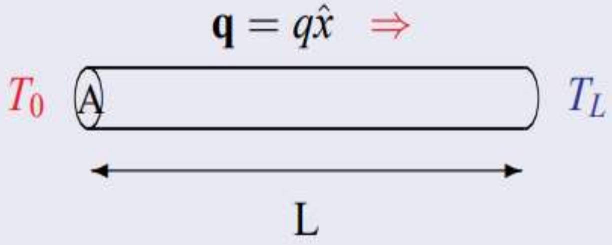
Radiation: Hot object → T^4 EM radiation

Ex. Solar, earth radiation

Heat conduction from Fourier law $\mathbf{q} = -k\nabla T$

—Analogy with electric conductivity $[\mathbf{j} = -\sigma\nabla V]$

Example: 1D problem: thin bar, length L, area $A \rightarrow \mathbf{q} = q\hat{x}$



Solve for $T(x), q(x)$ constant in time with fixed boundary conditions

- No change in time $\Rightarrow q$ constant in x (or T changes locally in time)

$\Rightarrow q = -k\frac{dT}{dx}$ = constant $\Rightarrow T(x) = T_0 + (T_L - T_0)\frac{x}{L}, \quad q = -k\frac{T_L - T_0}{L}$

Rate of heat transfer:

"thermal resistance"

$$qA = \frac{-k(T_L - T_0)A}{L} \Rightarrow T_L - T_0 = (qA)\left(\frac{L}{Ak}\right) \sim V = IR$$

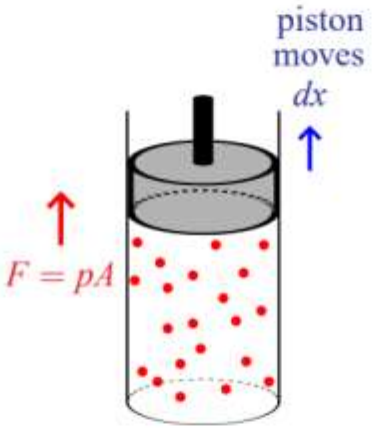
Heat conduction: example

Heat xfer through 0.2m concrete

material	k [W/mK]
air	0.026
fiberglass insulation	0.043
hard wood	0.16
concrete	1.4
steel	52

$$q = -k\frac{\Delta T}{L} = (1.4\ \mathrm{W/mK})(20\ \mathrm{K}/0.2\ \mathrm{m}) = 140\ \mathrm{W/m^2}$$

Expansion



Now, heat up air in cylinder

p increases $\Rightarrow$ piston moves

Work done by gas:

$$dW = Fdx = pAdx = pdV$$

So dU = -pdV

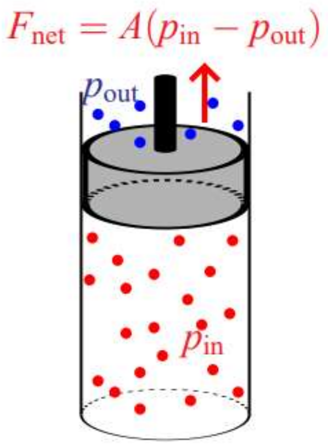
First Law of Thermodynamics

heat input $dQ \Rightarrow \quad dQ = dU + p\,dV$

Heat engine: Raise T $\Rightarrow$ Raise p $\rightarrow$ expand + do work $\Rightarrow$ cycle

Question: how much thermal energy can be used?

How much useful work can we get from thermal energy?

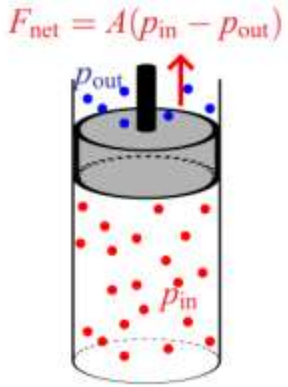


Work done when piston moves dx:
$dW = p_{\text{in}} dV.$

Some is work on outside gas
$dW_{\text{lost}} = p_{\text{out}} dV.$

Usable work is $dW_{\text{useful}} = (p_{\text{in}} - p_{\text{out}})dV.$

Enthalpy



Recall specific heat at constant volume
$dU = dQ = C_V dT \quad \Rightarrow \quad C_V = \left(\frac{\partial U}{\partial T}\right)_V$

At constant p, some energy $\rightarrow pdV$ work

$$dU + pdV = dQ = C_p dT$$

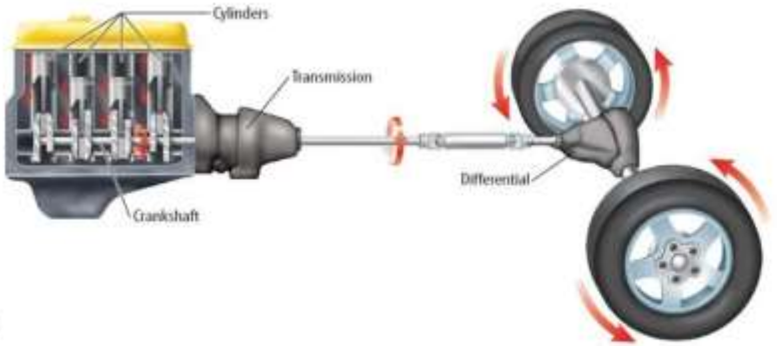
Define Enthalpy: $H = U + pV$ at constant pressure

so $dH = d(U + pV)_p = dU + pdV = C_p dT \quad \Rightarrow \quad C_p = \left(\frac{\partial H}{\partial T}\right)_p$

Converting Thermal Energy to Mechanical Energy

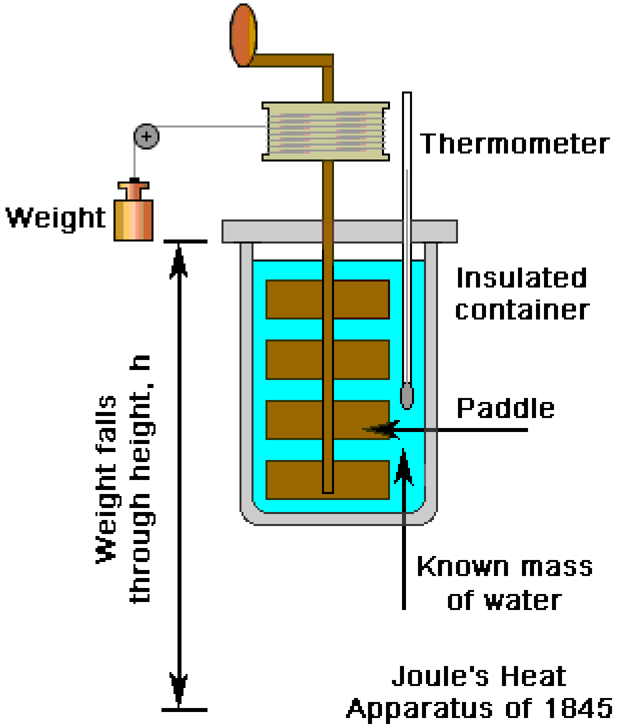
A device that converts thermal energy into mechanical energy is a **HEAT ENGINE**.

- A car's engine converts the chemical energy in gasoline into thermal energy.
- The engine then **TRANSFORMS** some of the thermal energy into mechanical energy by rotating the car's wheels.

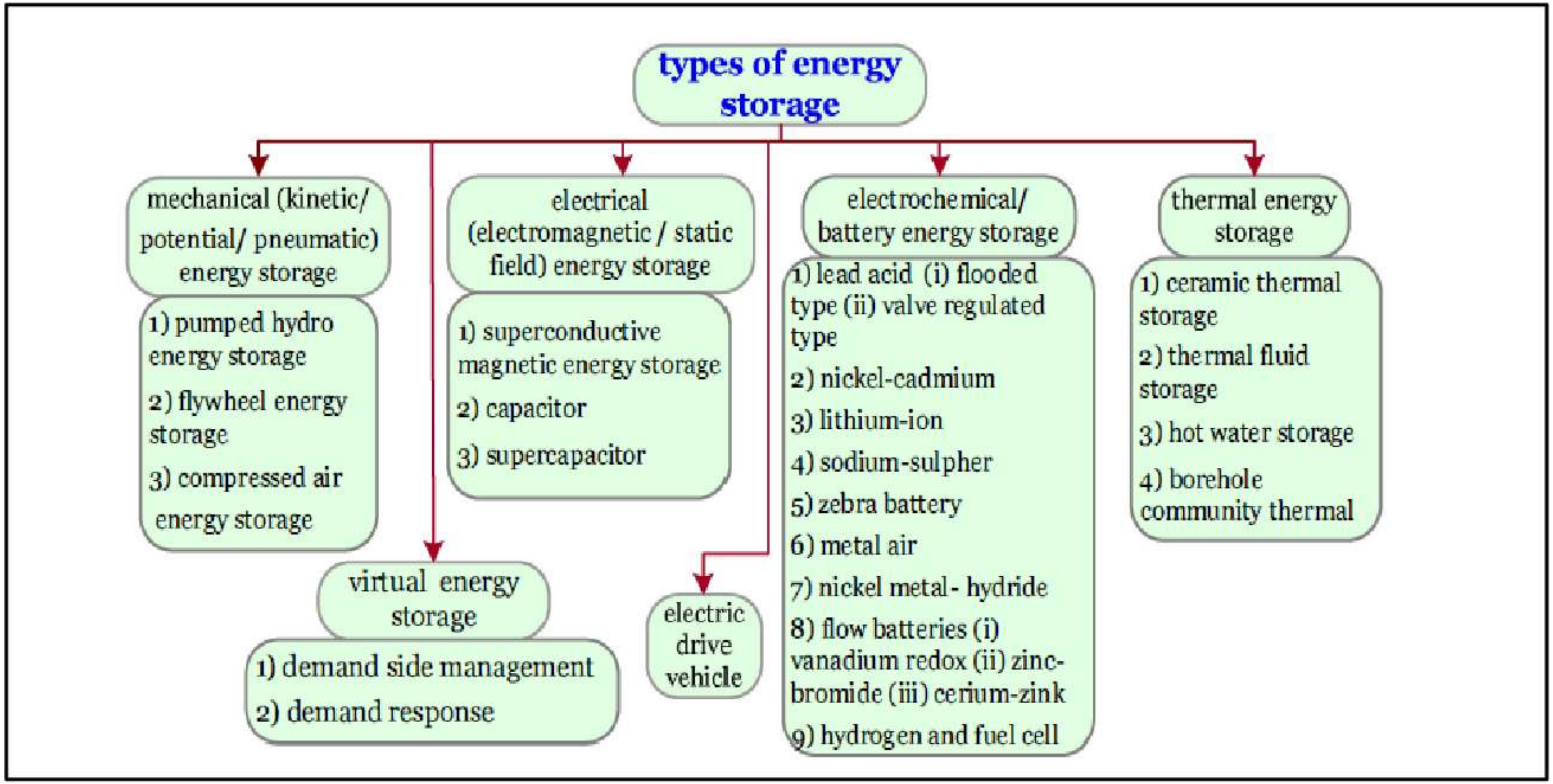


Using Thermal Energy

converting mechanical energy to thermal energy



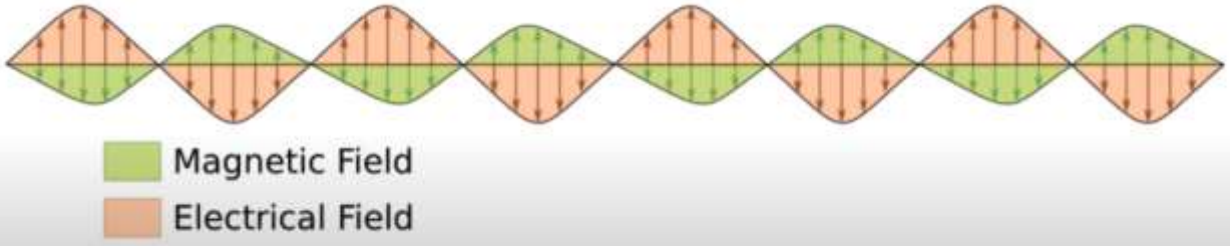
Energy storage is the capture of energy produced at one time for use at a later time.



Electromagnetic energy: Storage, conversion, transmission and radiation

Electromagnetic energy is released when an electrical charge is **accelerated** by an **external force**.

The acceleration creates a wave of alternating electrical and magnetic fields that separates from the charge and move off into space.



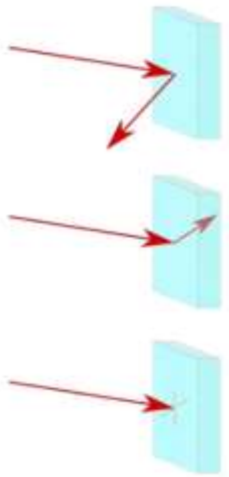
Electromagnetic Energy has wavelike and particle like properties

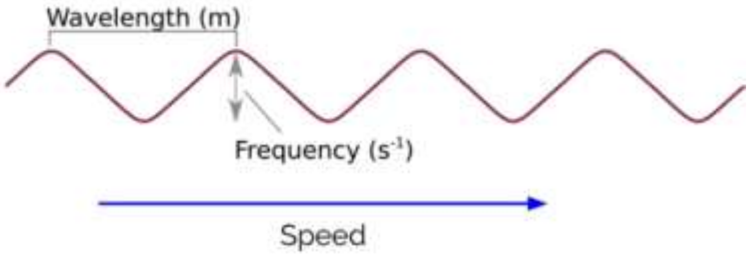
When an electromagnetic wave encounters matter it does one of 3 things:

It is Reflected

It Passes Through

It is Absorbed



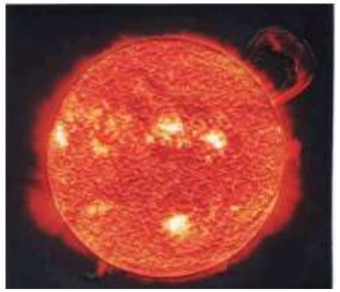


Wavelength	=	λ	(m)
Frequency	=	f	(s^{-1})
Speed	=	c	(m/s)

Scale of EM energy use...

- All solar energy is transmitted to earth as electromagnetic waves. Total yearly solar input,

$$1.74 \times 10^{17}\ \text{W} \quad \Rightarrow \quad 5.46 \times 10^{24}\ \text{J/year}$$



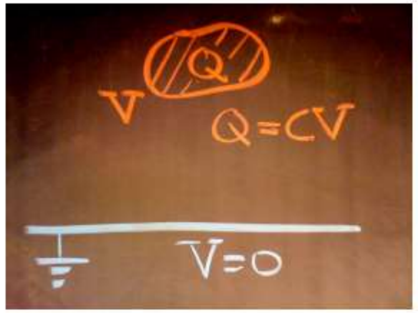
Increase capacitance:

- Increase effective surface area: gels, nanostructures
- Increase dielectric constant (polarizable but non-conducting materials)
- Decrease effective separation

Electromagnetic energy storage: capacitors

General idea of a capacitor:

- Place a charge Q on a conductor
- Voltage on the conductor is proportional to Q.



- Capacitance is proportionality constant

$$Q = C\,V$$

"Capacity" of conductor to store charge.

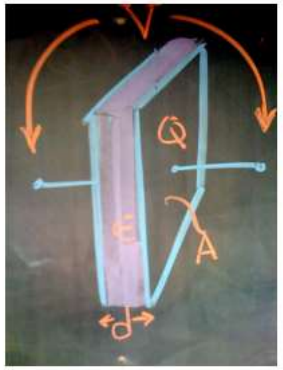
- Energy stored in a capacitor:

It takes work to move each little bit of charge through the electric field and onto the conductor.

$$\boxed{U = \frac{1}{2} C V^2}$$

Parallel plate capacitor

- Two plates, area A,
- Separation d,
- Filled with dielectric with dielectric constant $\epsilon = k\epsilon_0$



For parallel plates $C = \dfrac{\epsilon A}{d}$

To increase capacitance: increase Area (size limitations); decrease distance (charge leakage); or increase dielectric constant (material limitations)

For a parallel plate capacitor with $\epsilon = k\epsilon_0$

So typical scale for a capacitive circuit element is pico farads: 1 picofarad $= 1 \times 10^{-12}$

Electrical energy storage?

- Batteries are expensive, heavy, involve relatively rare and unusual materials (eg. lithium, mercury, cadmium,...), toxic.
- Storing electrical energy in capacitors is not a new idea, but using novel materials to make "ultra" capacitors is!

"Super" or "Ultra" Capacitors

Using sophisticated materials technology, capable of tens or even thousands of farad capacitors in relatively modest volumes.

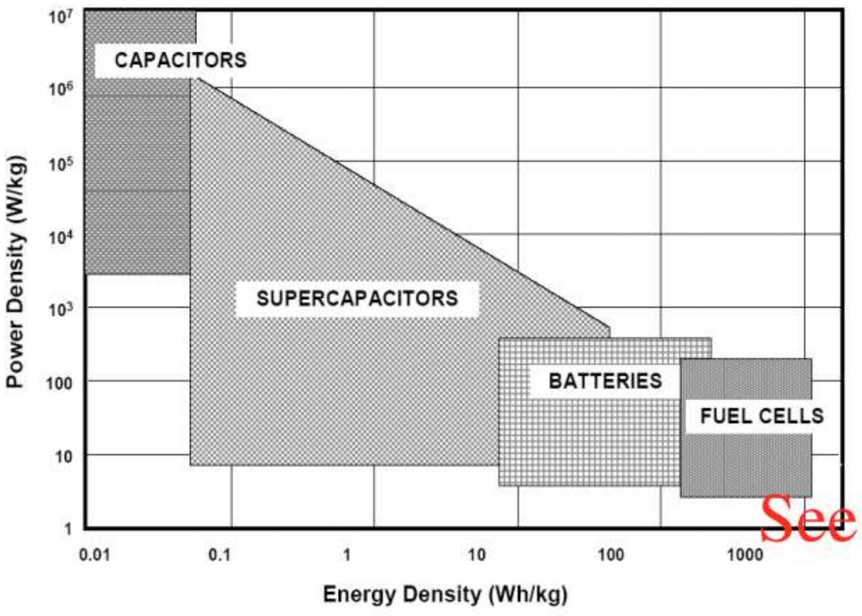
Compare with conventional rechargeable (*e.g.* NiMH) battery

Advantages

- Discharge and charge rapidly $\Rightarrow$ high power
- Vastly greater number of power cycles
- No environmental disposal issues
- Very low internal resistance (low heating)

Disadvantages

- Low total energy
- Intrinsically low voltage cell
- Voltage drops linearly with discharge
- Leakage times ranging from hours (electrolytic) to months



Resistive energy loss

Electric current passing through a resistance generates heat.

- Resistive energy loss in transmission of electric power is a major impediment to long distance energy transmission.
- Resistance converts electrical energy to heat at nearly 100% efficiency, but that's not the whole story.

Electric space heating — GOOD??

Transmission losses — BAD

Power lines: losses in transmission of electromagnetic energy

Transmission of energy over long distances is problematic.

- Oil & Gas — TANKERS & PIPELINE
- Coal & Nuclear — MINES & TRAINS
- Wind, solar, hydro, tidal — ELECTRICAL

So the process

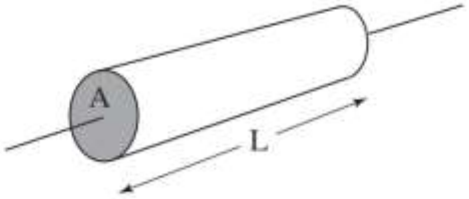
WIND / SOLAR / HYDRO } $\xrightarrow{\text{conversion}}$ losses — ELECTRICITY — $\xrightarrow{\text{transmission}}$ losses — SUBSTATION — $\xrightarrow{\text{conversion}}$ losses — USE

Is essential in a world where renewable energy plays a major role

Transmission losses NEXT
Conversion losses STAY TUNED

Cable

- Resistance grows linearly with length
- Resistance falls linearly with area



$$R = \frac{\rho L}{A}$$

$$\rho = \frac{RA}{L} \qquad \rho \equiv \text{resistivity}$$

$$[\rho] = [R][A/L] = \text{ohm-meter } (\Omega\text{-m})$$

Notice resemblance to heat conduction!

Design a cable

Resistivities:

- $\rho[\mathrm{Cu}] = 1.8 \times 10^{-8}\ \Omega$-m
- $\rho[\mathrm{Al}] = 2.82 \times 10^{-8}\ \Omega$-m
- $\rho[\mathrm{Fe}] = 1.0 \times 10^{-7}\ \Omega$-m

Material properties influencing choice:

- Light: Al > Cu > Fe
- Strong: Fe > Al, Cu
- Good conductor: Cu > Al > Fe
- Not subject to significant corrosion: Al > Cu > Fe
- Cost: Fe > Al > Cu

Transforming (to and from) Electromagnetic Energy

- Dynamos/motors
- Phases and Power
- Transformers

Basic idea: Induction

Time changing magnetic field induces an electric field.

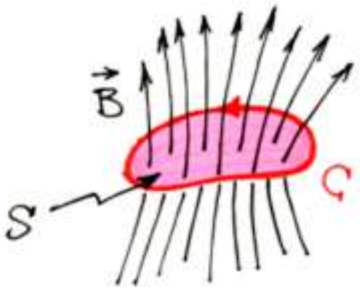
- Dynamos/motors

Long range transmission ⇒ electromagnetic forms. Hence

MECHANICAL ENERGY GENERATION → EM TRANSMISSION → MECHANICAL ENERGY USE

All based on Faraday's Law of Induction

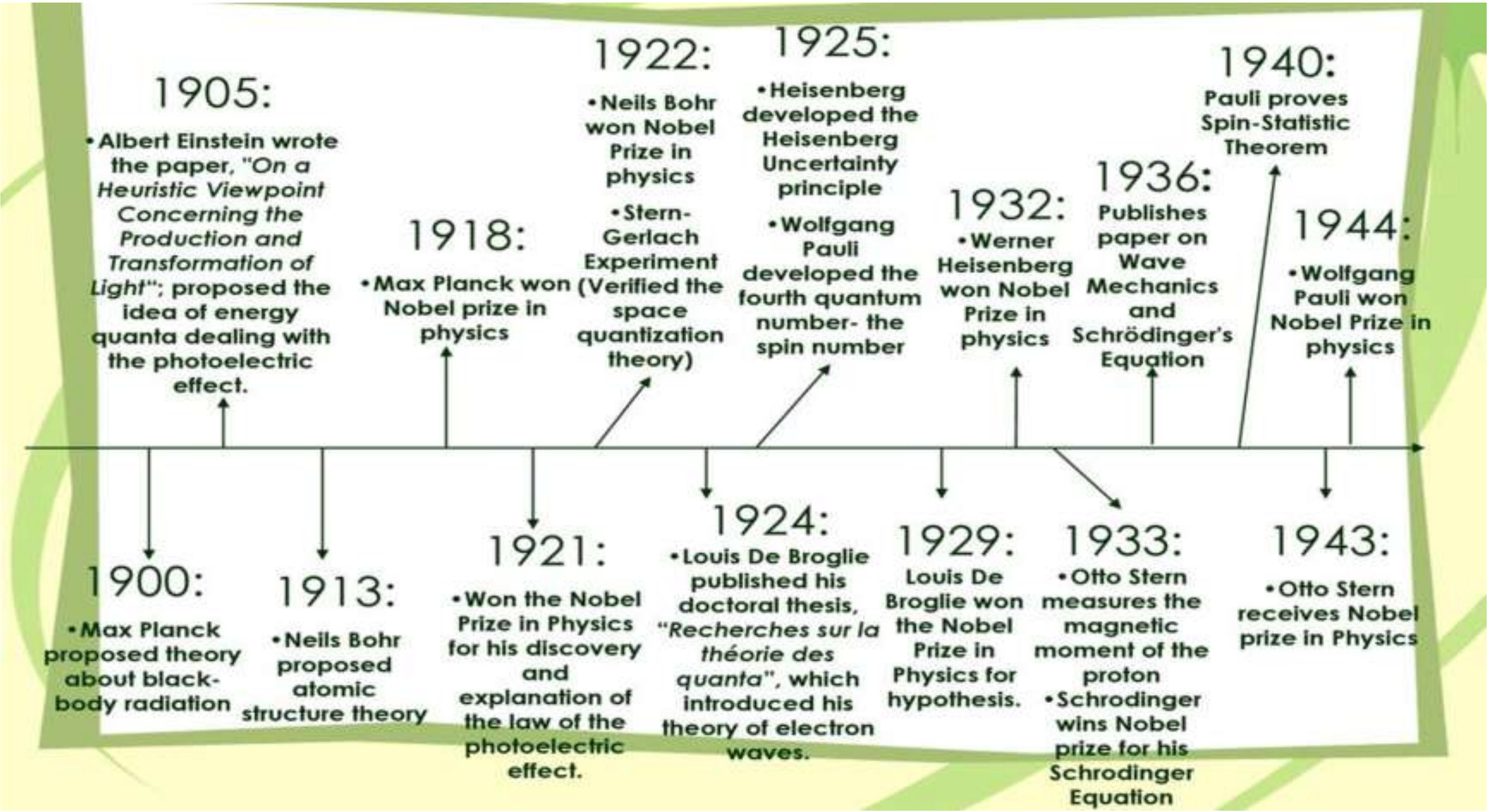
$$\oint_C \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \iint_S \vec{B} \cdot d\vec{A}$$



Quantum Mechanics

Quantum mechanics is the study of how atomic particles exist and interact with each other.

Classical mechanics allows scientists to make very accurate predictions for big objects. But these predictions do not work as well when you look at objects on a smaller scale. This is where quantum mechanics comes in. It describes laws of energy on the scale of atoms. The best way to understand quantum mechanics is through the history of its major discoveries.

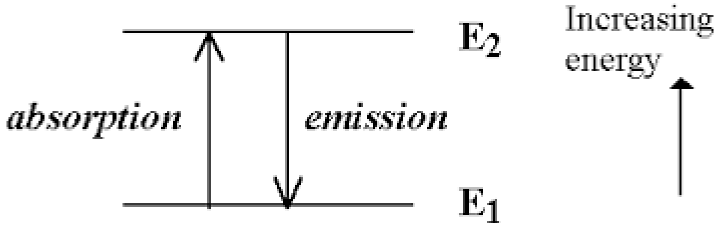


Energy quantization

- The **quantization** of **energy** refers to the absorption or emission of **energy** in discreet packets, or quanta.
- As the intensity of electromagnetic **energy** increases or decreases, it steps up or down from one **quantized** level to another, rather than follow a smooth and continuous curve.
- The establishment of energy quantization called for the replacement of classical mechanics
- Energy quantization became evident under three main studies
  - ❖ The black-body radiation
  - ❖ Heat capacities
  - ❖ Atomic and molecular spectra

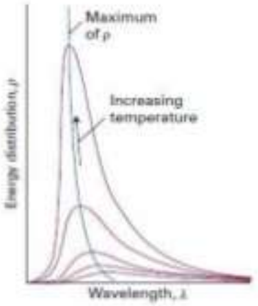
Potential energy of person walking up steps increases in stepwise, quantized manner

Potential energy of person walking up ramp increases in uniform, continuous manner



Black Body Radiation

- Black body is a material capable of emitting and absorbing all wavelengths of radiations uniformly.
- The classical approach to the description of black-body radiation results in the ultraviolet catastrophe.
- The prediction of classical physics that an ideal black body at thermal equilibrium will emit radiation in all frequency ranges, emitting more energy as the frequency increases.
- The sum of emissions in all frequency ranges suggest that a blackbody would release an infinite amount of energy, contradicting the principles of conservation of energy
- This drew attention to the need of a new model for the behavior of blackbodies



Chemical systems and processes, flow of CO2

Chemical (and Biological) Energy

SOURCES

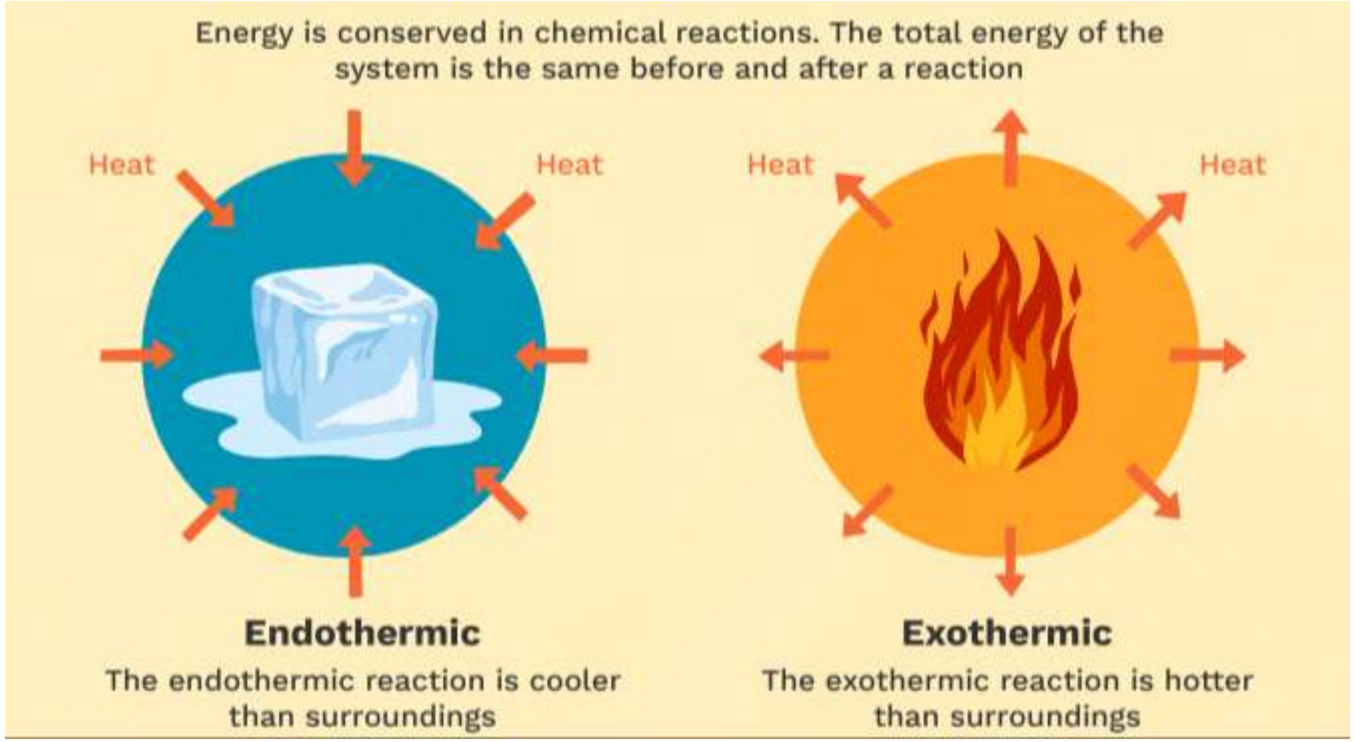
- Fossil fuels
- Biofuels
- Wood, waste, etc.

TRANS FORMATION AND STORAGE

• Batteries	Chemical $\leftrightarrow$ Electrical
• Fuel Cells	Chemical $\leftrightarrow$ Electrical
• Engines	$\left.\begin{array}{c}\text{Bio}\\ \text{Chemical}\end{array}\right\} \leftrightarrow$ Mechanical
• Working fluids	Mechanical $\leftrightarrow$ Heat
• Photosynthesis	Radiation $\leftrightarrow$ Biochemical

USES

- Heating & Cooling
- Transportation
- Manufacturing
- ...



Summary

- Internal energy is the energy that is stored in the system as potential or kinetic (thermal) energy when a system is put together from its pieces.
- Only *changes in internal energy* are observable. (Usually we omit rest mass energy of protons and neutrons when considering internal energy of H_2O.)
- The kinds of internal energy we should consider are dictated by the circumstances — chemical binding for chemistry, nuclear binding for nuclear processes.
- Enthalpy $H = U + pV \quad \Delta H = \Delta U + p\Delta V$ is the energy that must be added to a mechanical system to change the internal energy. Includes energy needed to perform "pdV work".
- Enthalphy of formation is the energy necessary to form a chemical compound out of its (molecular) constituents, including pdV work.
- If enthalpy must be added to a system to enable a reaction (eg. ionization) the process is endothermic. If energy is given off (eg. condensation of a gas) the process is exothermic.

Some useful heat capacities

Substance	Specific Heat Capacity KJ/kg K	Molar Heat Capacity J/mol K
Ice	2.09	37
Water	4.19	75
Steam	2.01	34
Ethanol(l)	2.42	113
Copper	0.38	33
Liquid sodium	1.39	32
Air	0.73	21
Helium	3.125	12.5

Substance	Specific Heat Capacity KJ/kg K
Steel	0.51
Glass	0.78
Granite	0.80
Wood	1.67
Soil	1.05

Lots of stories here!

Enthalpy of Reaction and Combustion

- Need to know how much energy is liberated when a particular reaction takes place.
- Strategy: Combine Enthalpies of formation (ΔH^f) to obtain the reaction of interest:
- Want $\Delta H_{\text{reaction}}$ for $A + B \rightarrow C + D$
- Again note the sign: $\Delta H_{\text{reaction}}$ is the change in the internal enthalpy of the products relative to the reactants, so $-\Delta H_{\text{reaction}}$ is the enthalpy given off to the environment.

General Result: For a reaction Reactants $\rightarrow$ products

- In a reaction you are forming the products and unforming the reactants
- So (Hess's Law)

$$\boxed{\Delta H(\text{Reaction}) = \sum_{\text{products}} \Delta H^f - \sum_{\text{reactants}} \Delta H^f}$$

- And $-H(\text{reaction})$ is given off to the environment

General Result: For a reaction Reactants $\rightarrow$ products

$$\text{Reactants} \rightarrow \text{Products} + \sum_{\text{reactants}} \Delta H^f - \sum_{\text{products}} \Delta H^f$$

$$\Delta H(\text{Reaction}) = \sum_{\text{products}} \Delta H^f - \sum_{\text{reactants}} \Delta H^f$$

(1) "Burning ethanol produces less CO_2 than burning gasoline."

Need a diversion to introduce the ideas of

Enthalpy of Reaction and Combustion

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- And $-H(\text{reaction})$ is given off to the environment

Compound	Chemical Formula	Enthalpy of Formation
Diatomic gases	H_2, O_2, Cl_2,...	0 kJ/mol (by definition)
Methane	$CH_4(g)$	– 75 kJ/mol
Water vapor	$H_2O(g)$	– 242 kJ/mol
Octane	$C_8H_{18}(l)$	– 250 kJ/mol
Ethanol liquid	$C_2H_5OH(l)$	– 278 kJ/mol
Carbon dioxide	$CO_2(g)$	– 394 kJ/mol
Calcium oxide	CaO	– 635 kJ/mol
Iron Ore (Hematite)	Fe_2O_3	– 824 kJ/mol
Calcium carbonate	$CaCO_3$	– 1207 kJ/mol
Sucrose	$C_6H_{12}O_6$	– 1270 kJ/mol

Example: Partial oxidation of octane to ethanol. Balanced chemical reaction:

$$C_8H_{18}(l) + \frac{7}{2} O_2(g) \rightarrow 3\, C_2H_5OH(l) + 2\, CO_2(g)$$

$$\begin{aligned} \Delta H_{\text{reaction}} &= 3\, \Delta H^f_{\text{ethanol}} + 2\, \Delta H^f_{CO_2} - \Delta H^f_{\text{octane}} \\ &= 3(-278\,\text{kJ/mol}) + 2(-394\,\text{kJ/mol}) - 1(-250\,\text{kJ/mol}) \\ &= -1372\,\text{kJ/mol} \end{aligned}$$

- Examples
  - ⋆ Combustion of methane $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  - ⋆ Combustion of ethanol $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
  - ⋆ Combustion of glycine $4C_2H_5NO_2 + 9O_2 \rightarrow 8CO_2 + 10H_2O + 2N_2$

(3) "Hydrogen is the fuel of the future!"

- If what you mean by a fuel is something that provides primary energy input to human activities, the answer is NO!
  - ⋆ It is not found on earth — there are no hydrogen mines!
  - ⋆ It takes at least as much energy to create H_2 from other sources as it yields when the hydrogen is burned.
- Hydrogen is a energy storage system. And a good one — in principle
- Energy content of hydrogen

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

$$\Delta H^f_{\text{water}}(l) = -285.83 \text{ kJ/mole}$$

- Enthalpy of H_2O liquid is 285.83 kJ/mole less than enthalpy of H_2 and (1/2) O_2, so burning hydrogen in oxygen is quite exothermic.
- Energy density of hydrogen:

$$(286 \text{ kJ/mole}) \div (2 \text{ gm } H_2\text{/mole}) = 143 \text{ MJ/kg}$$

A very large number (because hydrogen is so light.)

- Hydrogen: 143 MJ/kg
- Other energy storage systems:
  - ⋆ Methane: 56 MJ/kg
  - ⋆ Octane: 48 MJ/kg
  - ⋆ Ethanol: 31 MJ/kg
  - ⋆ Flywheel: ~ 0.5 MJ/kg
  - ⋆ NiMH Battery: ~ 0.22 MJ/kg
  - ⋆ Li Ion Battery: ~ 0.25 MJ/kg
- Hot water storage: H_2O at 100°C compared to 25°C: 0.314 MJ/kg. Very much smaller, but water is very easy to heat and very cheap to gather and store!

Energetics of making hydrogen

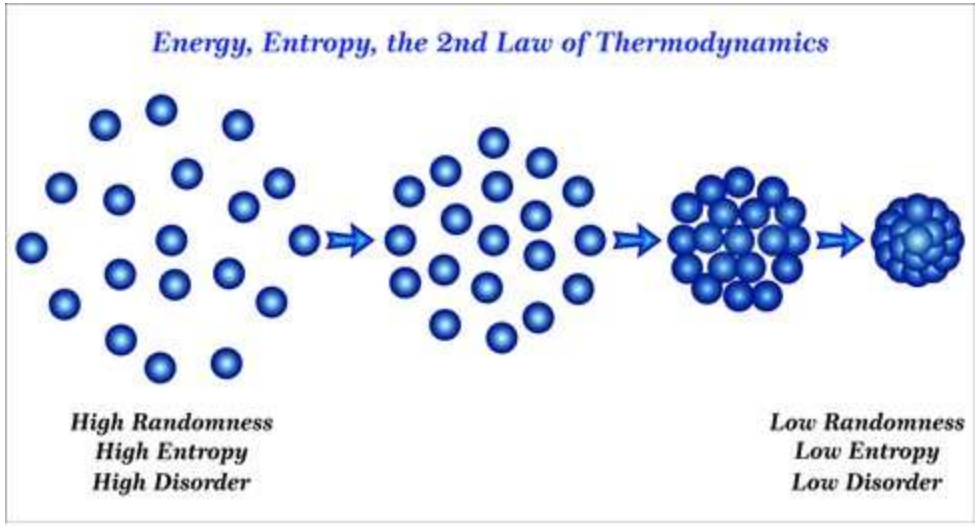
It all depends on the original energy source

Electrolysis:

- Pass a current through a solution of an electrolyte in water, producing hydrogen gas and oxygen gas at the electrodes.
- Efficiency depends on source of electric current.
  - ⋆ Efficiency for conversion of original energy source (hydro, nuclear, solar, wind, coal?) to electricity, including transmission losses: η_1.
  - ⋆ Efficiency of electrolysis: η_2.
  - ⋆ Efficiency of infrastructure (recovery, compression, transport, storage): η_3.
  - ⋆ Efficiency for useful work from combustion of hydrogen (or fuel cell): η_4.
  - ⋆ Efficiency if original energy source were converted directly to useful work, η^*.

Entropy

- There is a tendency in nature to proceed in a direction that increases the randomness of a system.
  - A random system is one that lacks a regular arrangement of its parts.
- This tendency toward randomness is called *entropy*.
  - **Entropy is a measure of chaos or disorder**
- **Entropy,** *S,* can be defined in a simple qualitative way as a measure of the degree of randomness of the particles, such as molecules, in a system.



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Entropy

1. Entropy is a <u>measure</u> of the disorder (or randomness) of a system
2. For reversible processes, entropy change is measured as the ratio of heat energy gained to the state temperature:

$$dS = \left(\frac{dQ}{T}\right)_{rev} \quad \text{or} \quad \Delta S_{rev} = S_{final} - S_{initial} = \int_i^f \frac{dQ}{T}$$

   a. When net heat flow is positive for a system, the system entropy increases (and lost by the surrounding environment)
   b. When net heat flow is negative, system entropy decreases (and gained by the surrounding environment)

3. The net entropy change by <u>a system</u> due to a completely (reversible) thermodynamic cycle operating between 2 defined constant temperature reservoirs:

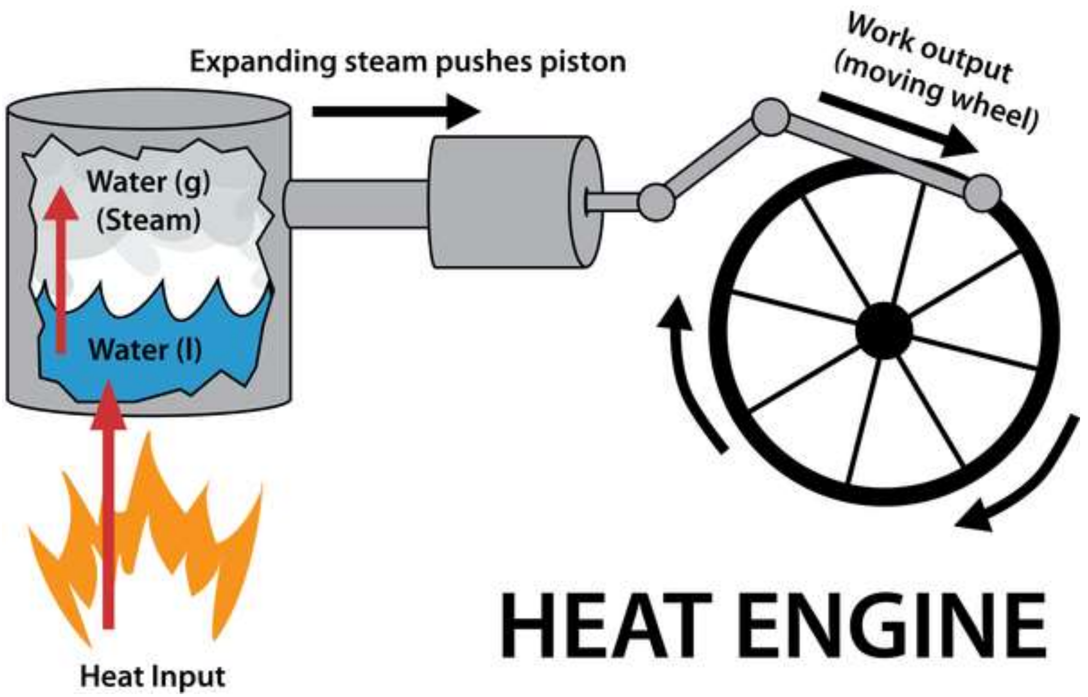
$$\Delta S_{system} = S_{gained} - S_{lost} = \frac{Q_{hot}}{T_{hot}} - \frac{Q_{cold}}{T_{cold}}$$

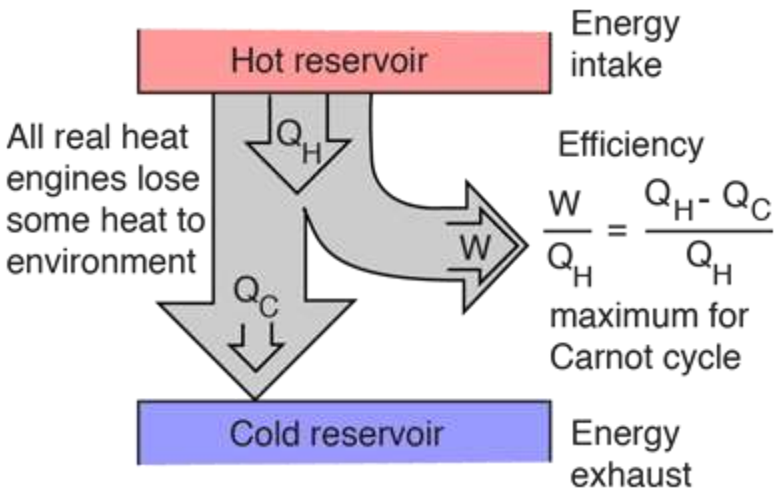
4. The total entropy of the universe ($S_{universe}$) will never decrease, it will either
   a. Remain unchanged (for a reversible process)
   b. Increase (for an irreversible process)
5. Entropy change is related to the amount of energy lost irretrievably by a thermodynamic process:

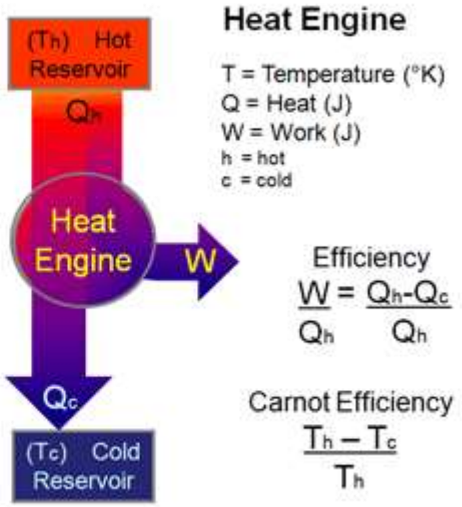
$$dW_{unavailable} = T_{cold} dS_{universe} \text{ or } W_{unavailable} = T_{cold} \Delta S_{universe}$$

What is Heat Engine?

- Heat Engine is the device which converts **chemical** energy of fuel into **heat** energy & this heat energy is utilized converting it to **mechanical** work.
- A **heat engine** is a system that performs the conversion of heat to mechanical energy which can then be used to do mechanical work.







Carnot Engine

- A theoretical engine developed by Sadi Carnot
- A heat engine operating in an ideal, reversible cycle (now called a *Carnot Cycle*) between two reservoirs is the most efficient engine possible
- *Carnot's Theorem*: No real engine operating between two energy reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs

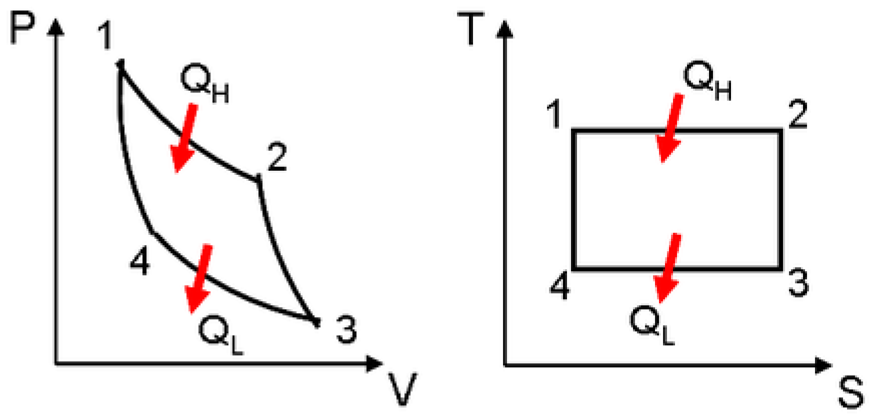
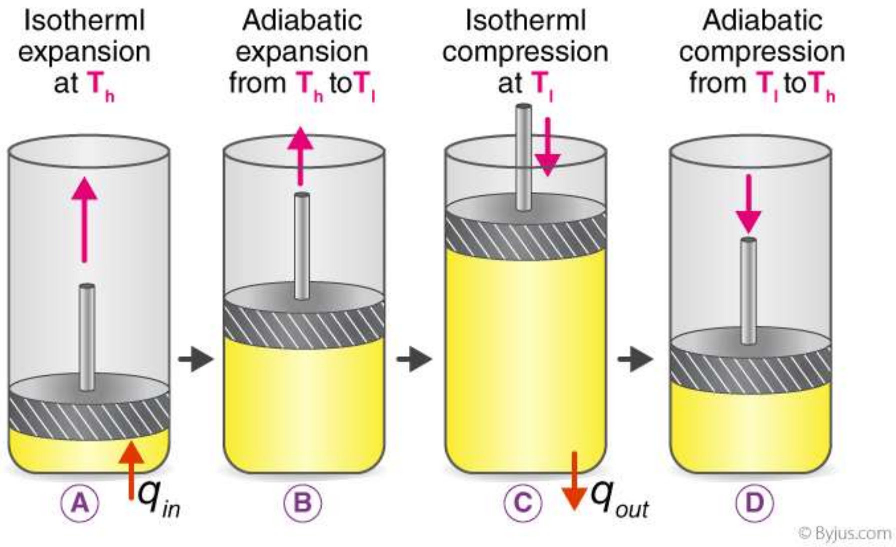
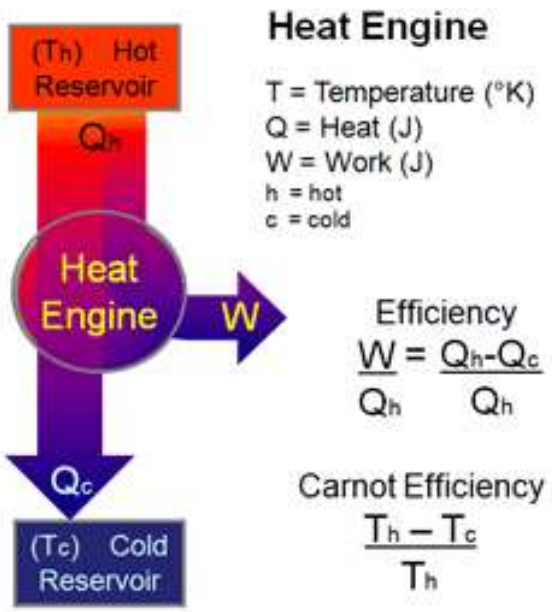


Fig.1. P-V and T-S diagrams of Carnot Cycle





Stirling Cycle

- The Stirling cycle consists of two isothermal and two isochoric processes.
- The p-V and T-s diagrams of Stirling cycle has been given below:

Idealised Stirling Cycle

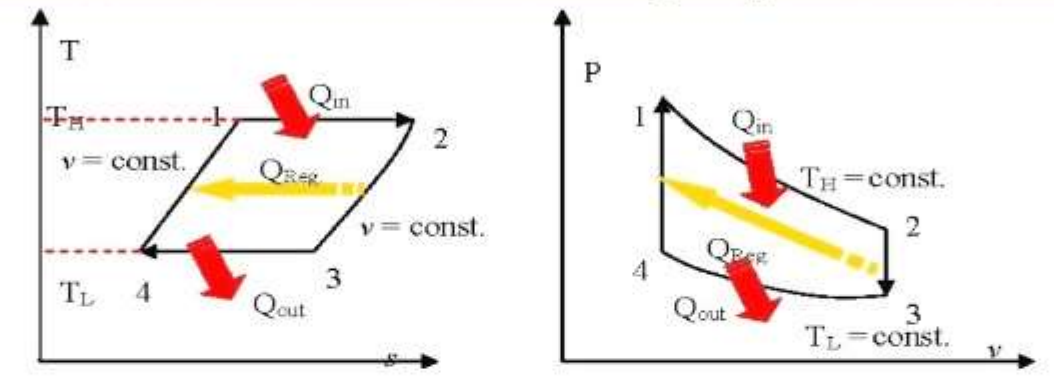


Fig. 3-2: T-s and P-v diagrams for Stirling cycle.

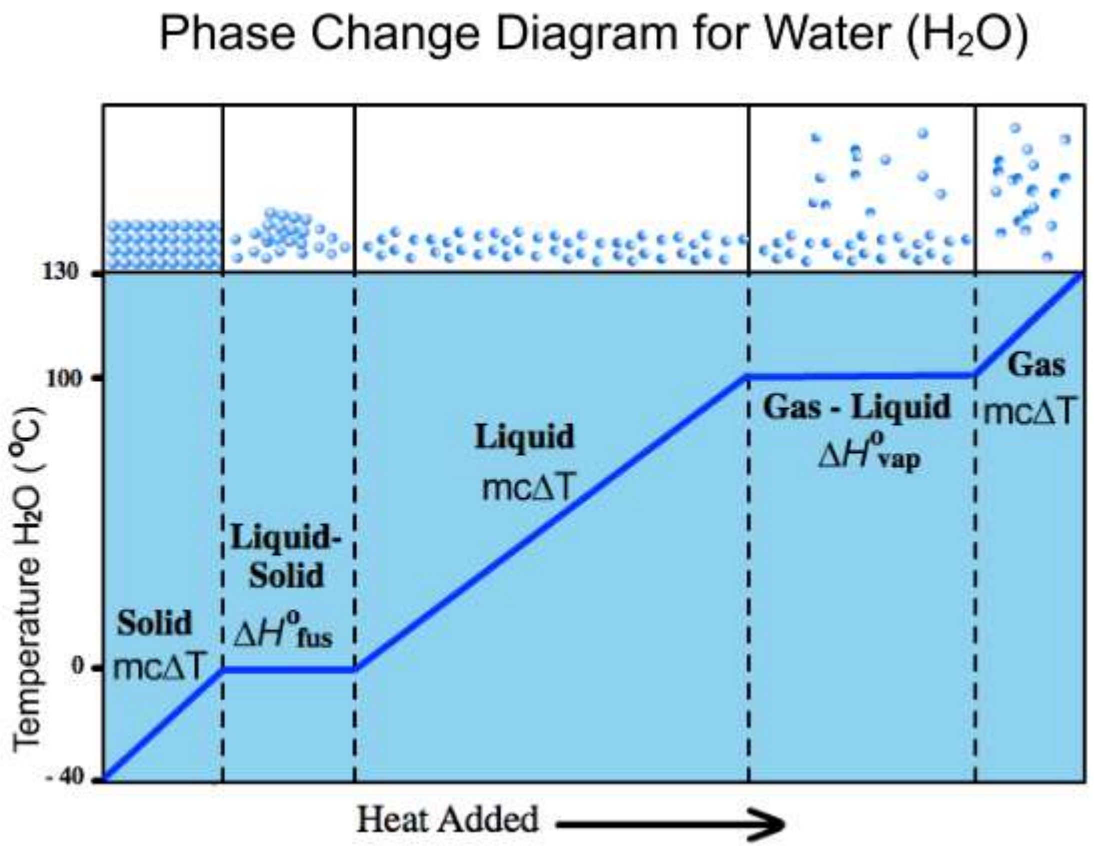
- 1-2 isothermal expansion heat addition from external source
- 2-3 const. vol. heat transfer internal heat transfer from the gas to the regenerator
- 3-4 isothermal compression heat rejection to the external sink
- 4-1 const. vol. heat transfer internal heat transfer from the regenerator to the gas

What is a Phase Change?

- Is a change from one state of matter (solid, liquid, gas) to another.
- Phase changes are **physical changes** because:
  - It only affects physical appearance, not chemical make-up.
  - Reversible

PHASE CHANGES

Description of Phase Change	Term for Phase Change	Heat Movement During Phase Change
Solid to liquid	Melting	Heat goes into the solid as it melts.
Liquid to solid	Freezing	Heat leaves the liquid as it freezes.



What Is Power Plant?

- A **power plant** or a **power generating station**, is basically an industrial location that is utilized for the generation and distribution of electric power in mass scale, usually in the order of several 1000 Watts.
- A power plant can be of several types depending mainly on the type of fuel used.

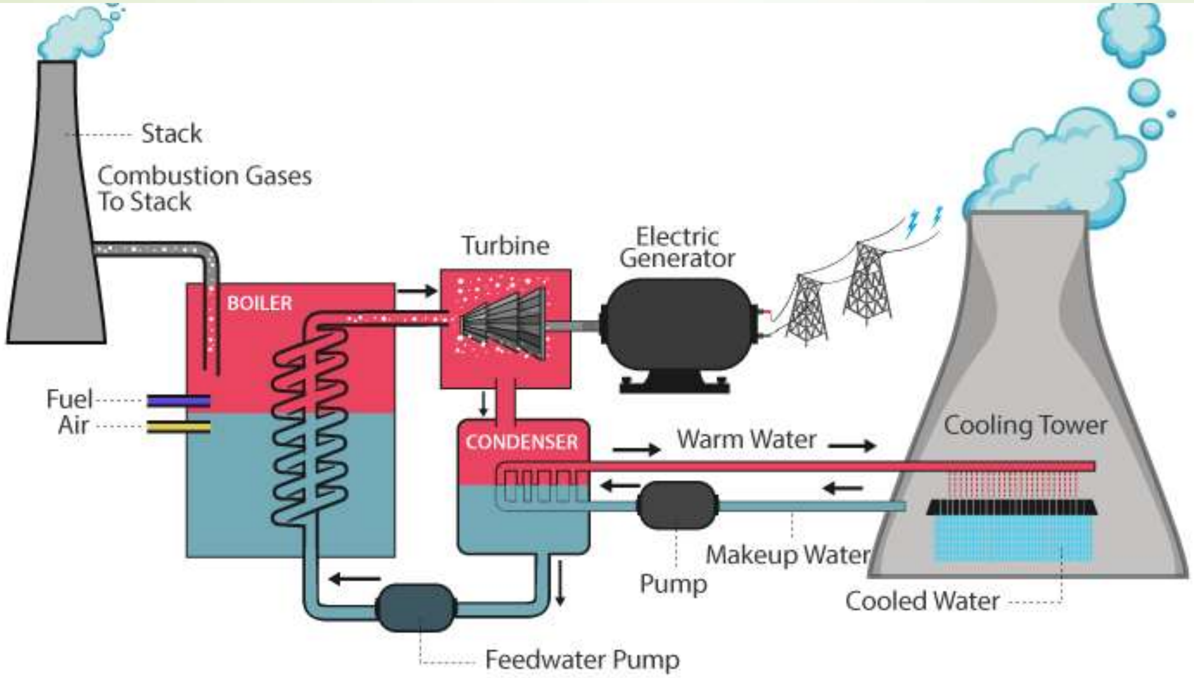
TYPES OF POWER PLANTS

1.BASED ON INPUT ENERGY /FUEL

(a.)COAL thermal Power Plants
(b.) HYDRAULIC Power Plants
(c.) NUCLEAR Power Plants
(d.) GEOTHERMAL Power Plants
(e.) SOLAR Power Plants
(f.)WIND power plants
(g.)BIOMASS power plant

Thermal power plant

A thermal power station or a coal fired thermal power plant is by far, the most conventional method of generating electric power with reasonably high efficiency. It uses coal as the primary fuel to boil the water available to superheated steam for driving the steam turbine. The steam turbine is then mechanically coupled to an alternator rotor, the rotation of which results in the generation of electric power. Generally in India, bituminous coal or brown coal are used as fuel of boiler which has volatile content ranging from 8 to 33% and ash content 5 to 16 %. To enhance the thermal efficiency of the plant, the coal is used in the boiler in its pulverized form.



The Rankine Cycle

The **Rankine cycle** is a cycle that converts heat into work. The heat is supplied externally to a closed loop. This cycle generates about 90% of all electric power used throughout the world The Rankine cycle is the fundamental thermodynamic underpinning of the steam engine and thermal power plant

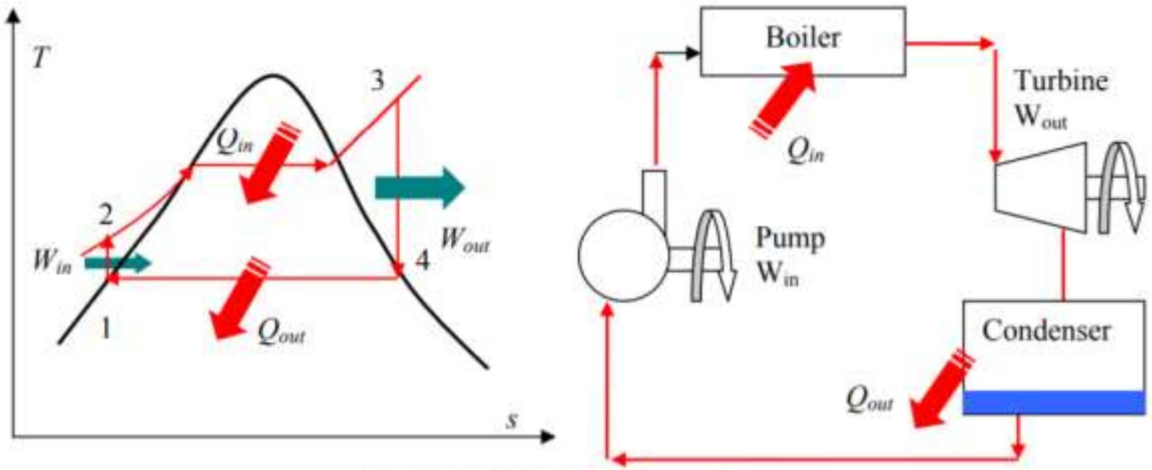


Fig. 2: The ideal Rankine cycle.

Energy Analysis for the Cycle

All four components of the Rankine cycle are steady-state steady-flow devices. The potential and kinetic energy effects can be neglected. The first law per unit mass of steam can be written as:

Pump	$q = 0$	$w_{pump,in} = h_2 - h_1$
Boiler	$w = 0$	$q_{in} = h_3 - h_2$
Turbine	$q = 0$	$w_{turbine,out} = h_3 - h_4$
Condenser	$w = 0$	$q_{out} = h_4 - h_1$

The thermal efficiency of the cycle is determined from:

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

where

$$w_{net} = q_{in} - q_{out} = w_{turbine,out} - w_{pump,in}$$

If we consider the fluid to be incompressible, the work input to the pump will be:

$$(h_2 - h_1) = v(P_2 - P_1)$$

where $h_1 = h_{f@P1}$ & $v = v_1 = v_{f@P1}$

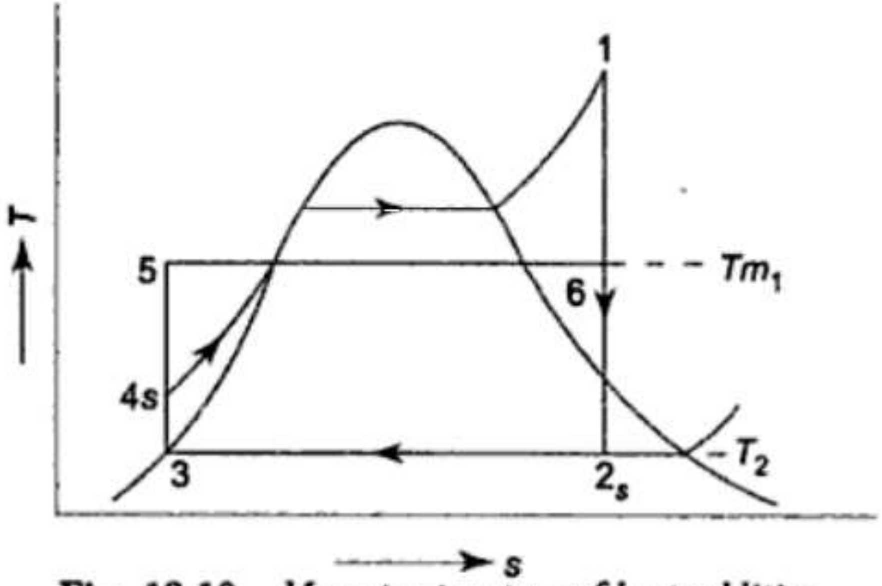


Fig. 12.10 *Mean temperature of heat addition*

$\eta_{rankine} = 1 - T_2 / T_m$ → Lowering the condenser pressure, Higher will be the efficiency of Rankine cycle.

Rankine cycles in other applications

- Solar thermal energy conversion
- Ocean thermal energy conversion

  Using ammonia or other fluid with appropriate thermodynamics
- Low temperature organic Rankine cycles (ORC)

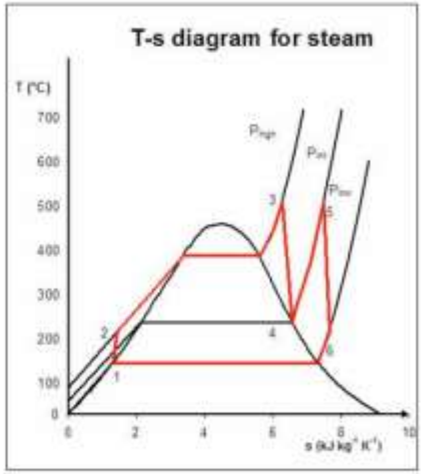
  Utilize low energy density sources like

  Biomass, low intensity solar, low temperature geothermal

  Using organic fluids (eg. pentane) with appropriate thermodynamics

So
re

More complex Rankine cycles



Rankine with reheating:

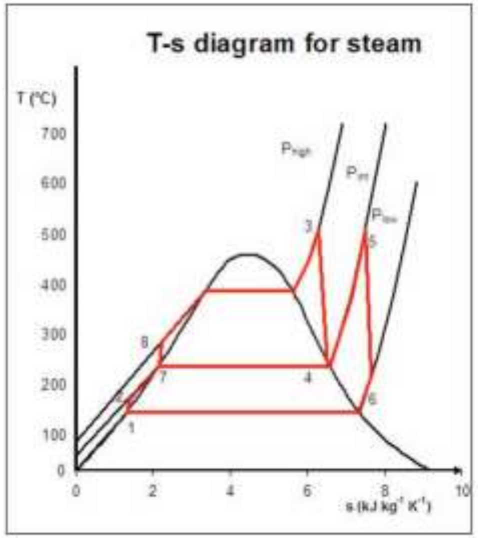
- Two turbines in series

  Output from one at ④

  Re-enters boiler without recompression

  Hence no decrease in entropy before reheating

  And then to second turbine



Rankine with regeneration:

- Commonly used in actual power plants
- Two turbines in series

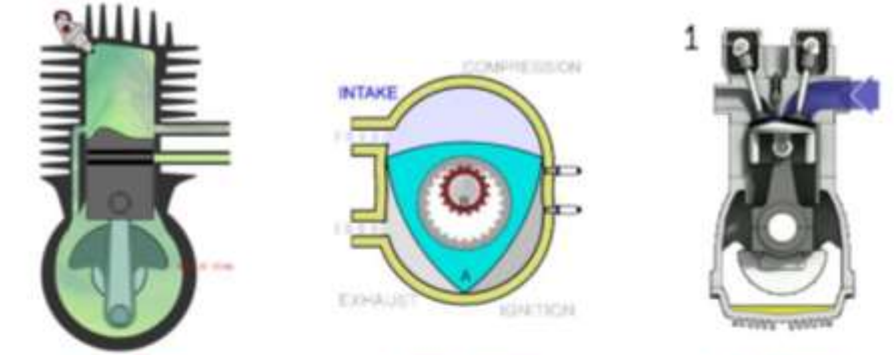
  Condensed subcooled liquid at ②

  Mixed with steam tapped at ④

  To preheat to saturated liquid at ⑦

Internal Combustion Engine

The **internal combustion engine** is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber.



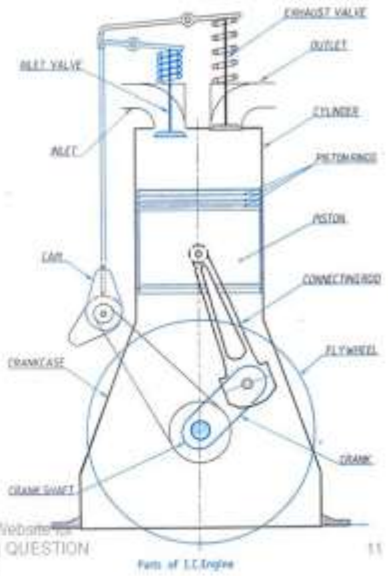
2 – Stroke Engine

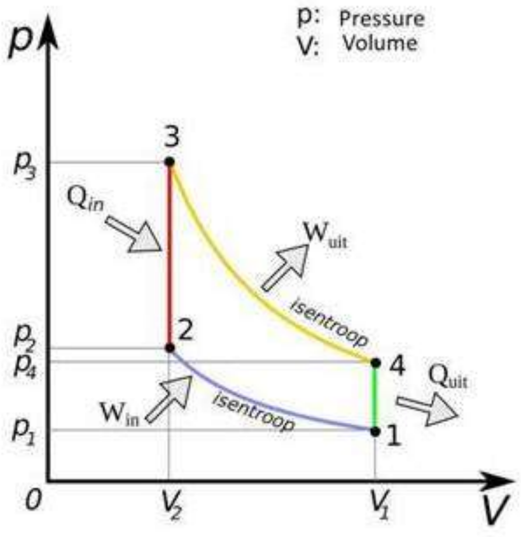
Rotay Engine

4 – Stroke Engine

Parts of I.C Engine

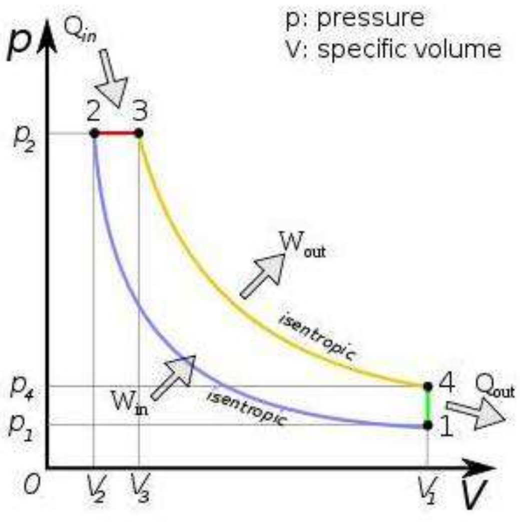
- *Cylinder*
- *Piston*
- *Piston rings*
- *Connecting rod*
- *Crank and crankshaft*
- *Valves*
- *Flywheel*
- *Crankcase*





Otto Cycle

VS



Diesel Cycle

	Otto Cycle	Diesel Cycle
1	Heat is addition in system at constant volume.	Heat is addition in system at constant pressure.
2	Compression ration varies from 6 to 10.	Compression ration varies from 14 to 22.
3	High Efficiency at same compression ratio.	Low efficiency at same compression ratio.
4	Petrol engine work on Otto cycle.	Diesel engine is work on diesel cycle.
5	Spark plug required.	Fuel injector required.
6	Air Fuel mixture inserted from inlet valve.	Only Air is inserted from inlet valve.
7	After generating spark, combustion take place.	Combustion take place due to hot air and fuel receive from fuel injector.
8	In compression stroke, air fuel is compressed.	In compression stroke, only air is compressed.
9	Fuel is inserted during the suction stroke.	Fuel is inserted at the end of compression stroke.
10	No need of high pressure and temperature because spark starts the combustion.	High pressure and temperature is required to start combustion when fuel is injected.
11	Low compression ratio.	High compression ratio.

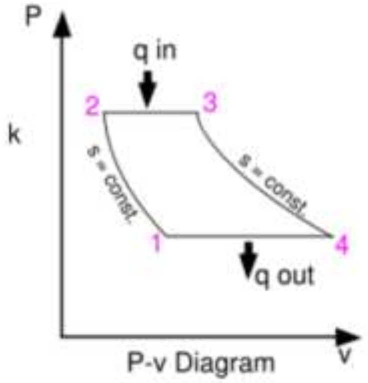
Brayton Gas Turbine Cycles

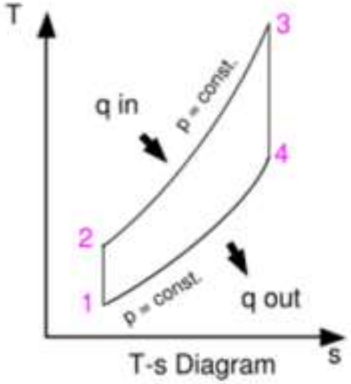
Open cycle gas fired turbine

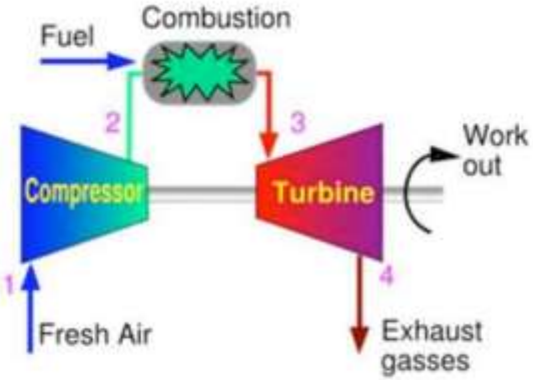
- ★ **What's the idea? Burn natural gas to produce high T and high P vapor**

  Directly powers turbine

- ★ **Very high temperatures $\sim 1200°$C and efficiencies $\sim 35-42\%$.**





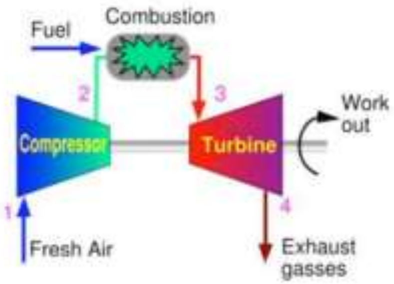


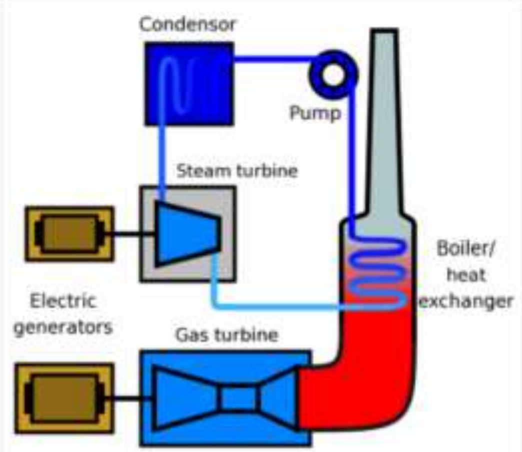
- ★ **Elements in cycle**
  - [12] Fresh air enters compressor: Adiabatic compression
  - [23] Combustion: Isobaric heating
  - [34] Turbine: Adiabatic expansion
  - [41] Exhaust: Isobaric cooling

Brayton Gas Turbine Cycles

Combine Brayton Gas Cycle with Rankine Steam Cycle

- ★ **Very high temperatures $\sim 1200°$C and efficiencies $\sim 35-42\%$.**
- ★ **By-product gases from gas turbine are hot enough, $\sim 500°$C to source a downstream Rankine cycle**
- ★ **Ideally combine with cogeneration for most greatest efficiency!**
- ★ **Efficiencies exceed 60 – 65 % compared to 30-40 % for separate Rankine or Brayton cycles (when using natural gas)**





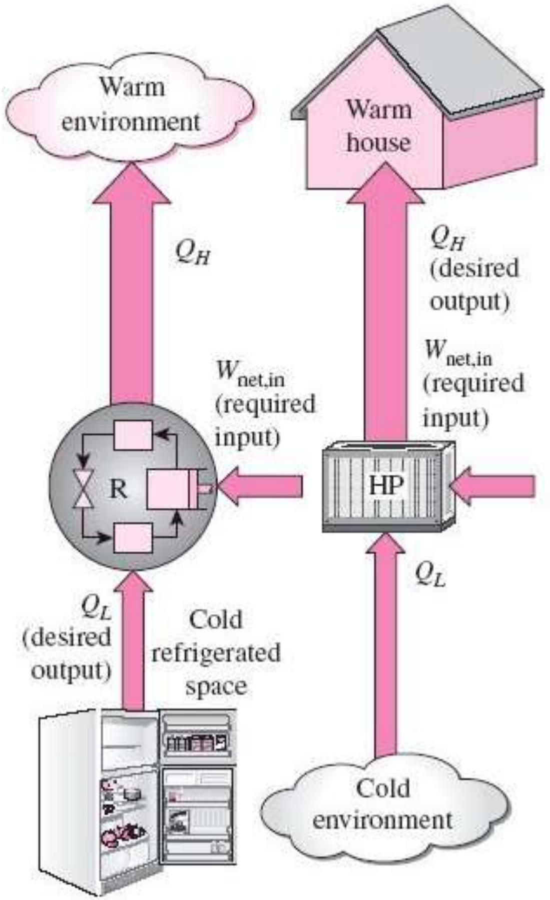
$$\eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

$$\eta = 1 - \frac{T_1\left[\left(\frac{T_4}{T_1}\right) - 1\right]}{T_2\left[\left(\frac{T_3}{T_2}\right) - 1\right]}$$

$$\eta_{\text{th, Brayton}} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_1}{P_2}\right)^{(k-1)/k}$$

$$= 1 - \frac{1}{r_P^{(k-1)/k}}$$

REFRIGERATORS AND HEAT PUMPS



(*a*) Refrigerator (*b*) Heat pump

- The transfer of heat from a low-temperature region to a high-temperature one requires special devices called **refrigerators**.
- Another device that transfers heat from a low-temperature medium to a high-temperature one is the **heat pump**.
- Refrigerators and heat pumps are essentially the same devices; they differ in their objectives only.
- The objective of a refrigerator is to remove heat (Q_L) from the cold medium
- The objective of a heat pump is to supply heat (Q_H) to a warm medium.

$$COP_{Heating} = \frac{T_{HOT}}{T_{HOT} - T_{COLD}}$$

$$COP_{COOLING} = \frac{T_{COLD}}{T_{HOT} - T_{COLD}}$$

Semiconductors

A semiconductor material is one which conducts only when excited.

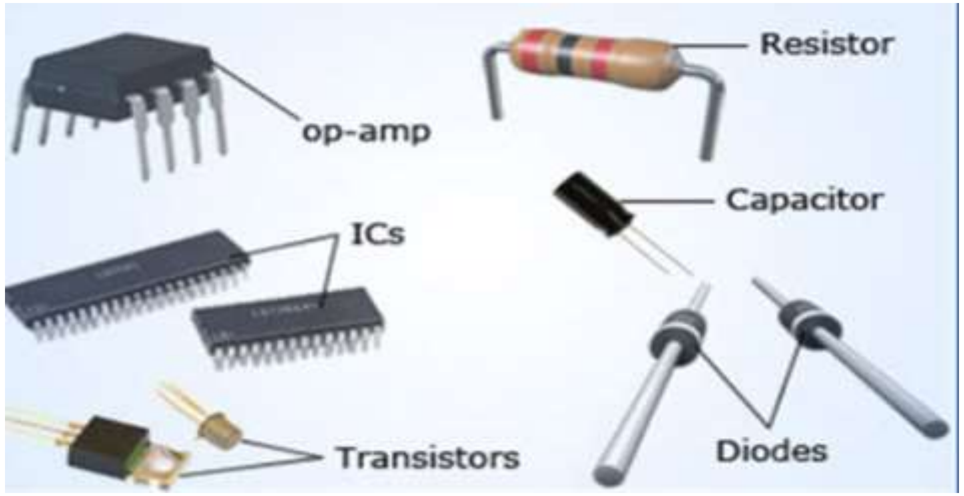
- It is neither an Insulator, nor a Conductor.
- A conductor has normally one carrier per atom, while a semiconductor has one carrier per 10^{12} at room temperature (Silicon).
- The devices are built by introducing an impurity into otherwise a pure matter, and the process is called "doping".

- **Semiconductor device,** electronic circuit component made from a material that is neither a good conductor nor a good insulator (hence semiconductor). Such devices have found wide applications because of their compactness, reliability, and low cost. As discrete components, they have found use in power devices, optical sensors, and light emitters, including solid-state lasers.
- Semiconductor device have high conductivities, typically from 10^4 to 10^6 Siemens per centimeter. The conductivities of semiconductors are between these extremes.

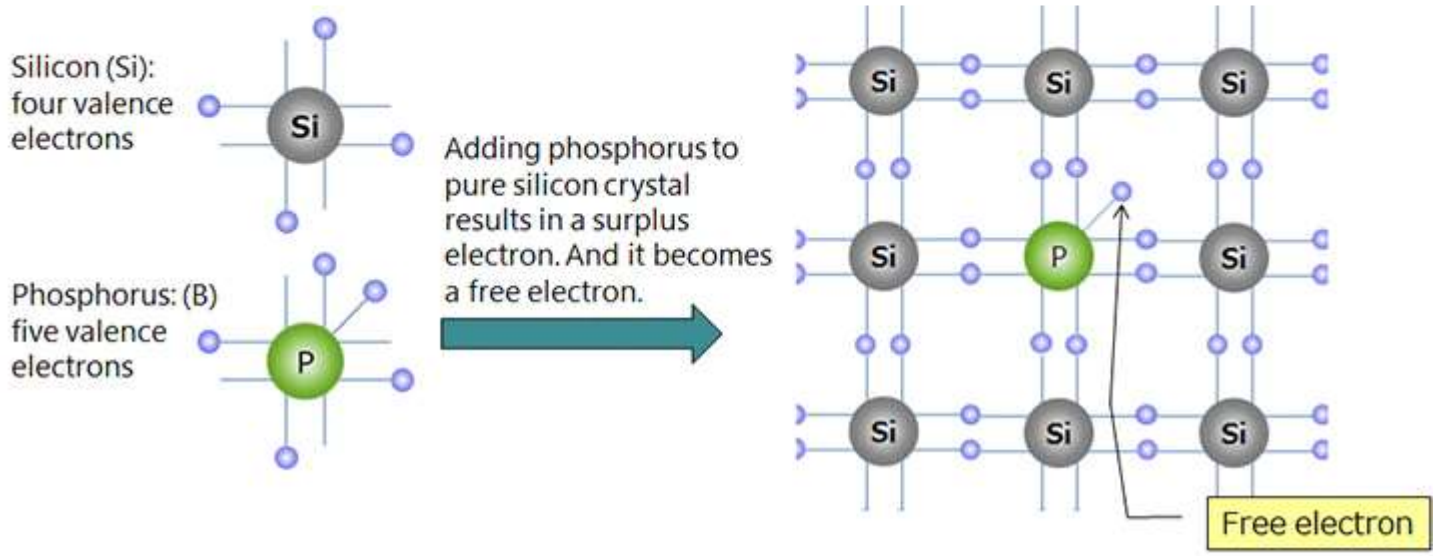
Applications of semiconductor devices

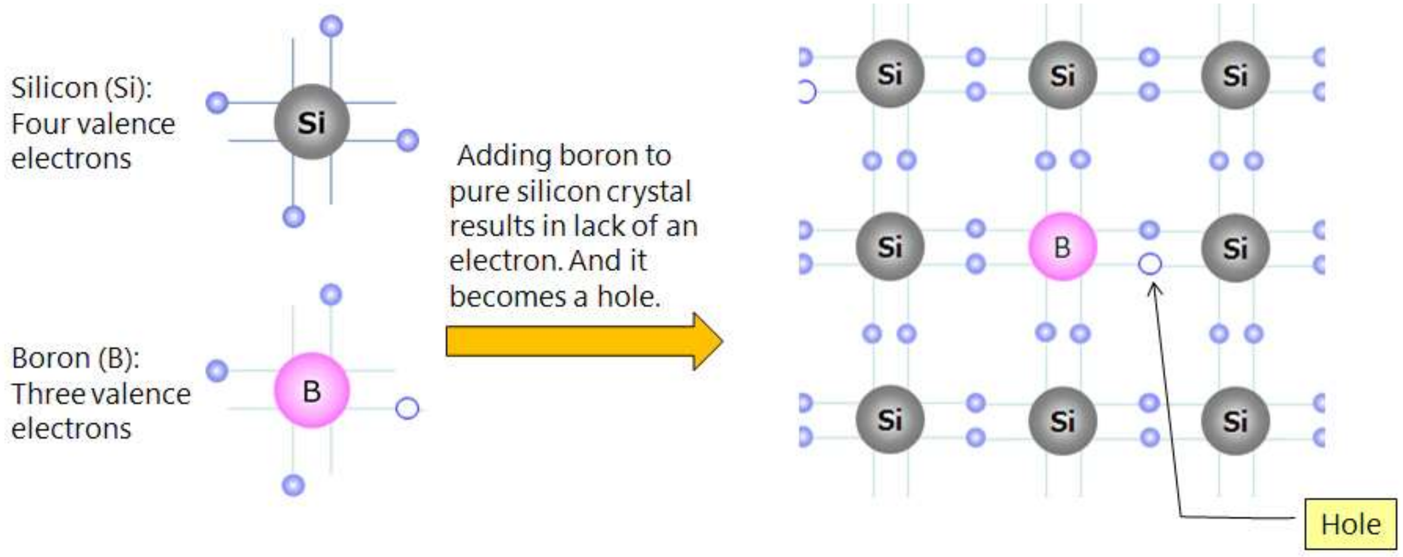
Semiconductor devices are all around us. . They can be found in just about every commercial product we touch, from the family car to the pocket calculator.

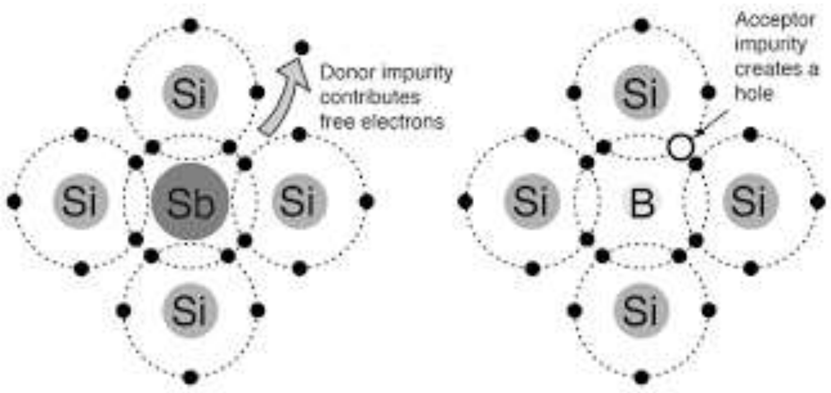
- Rectifiers which are used in d. c. power supplies.
- Wave shaping circuits such as clippers and clampers.
- Voltage regulator circuits.
- Portable Radios and TV receivers.
- Science and industry,
- solid-state devices, space systems, computers, and data processing equipment,
- military equipment,
- Data display systems, data processing units, computers, and aircraft guidance-control assemblies etc...



n and p type semiconductor



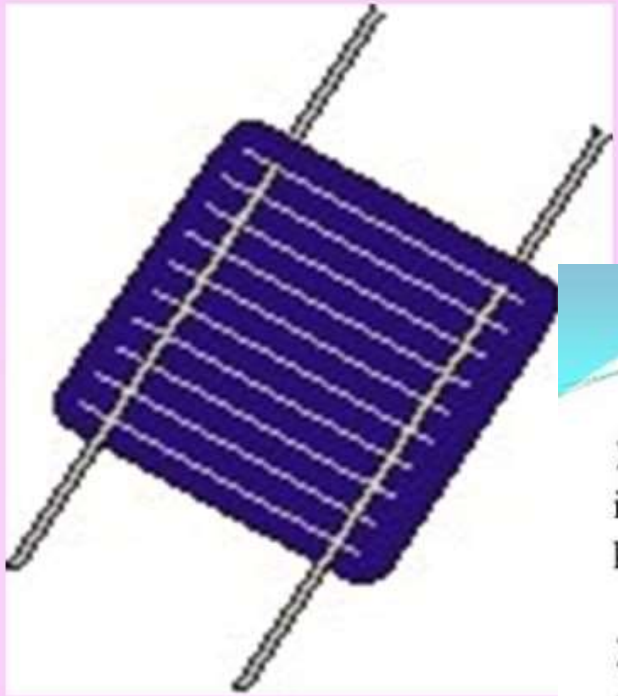




N-type semiconductor	P-type semiconductor
1. It is an extrinsic semi-conductor which is obtained by doping the impurity pentavalent impurity atoms such as antimony, phosphorous, arsenic etc. to the pure germanium or silicon semiconductor.	1. It is an extrinsic semiconductor which is obtained by doping trivalent impurity atoms such as boron, gallium, indium etc. to the pure germanium or silicon semiconductor.
2. The impurity atoms added, provide extra electrons in the structure, and are called donor atoms.	2. The impurity atoms added, create vacancies of electrons (i.e., holes) in the structure and are called acceptor atoms.
3. The electrons are majority charge carriers and holes are minority charge carriers.	3. The holes are majority charge carriers and eletrons are minority carriers.

What is a Solar Cell?

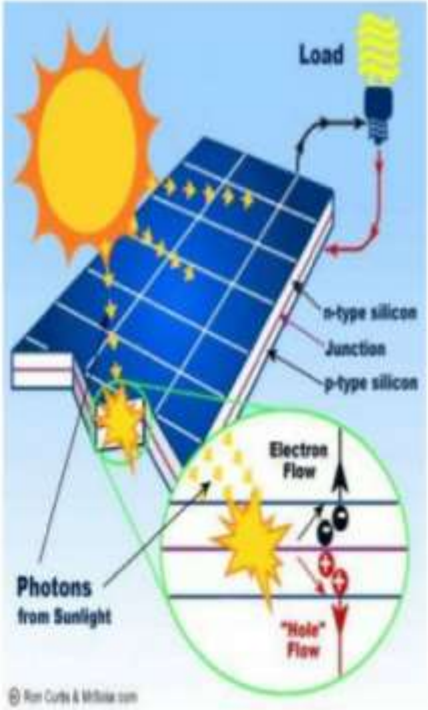
- A solar cell is a semiconductor device which converts electromagnetic radiation into electrical signals.
- It is a device which generates electricity directly from Sun's radiation by means of the photovoltaic effect so it is also called Photovoltaic cell.
- In order to generate useful power, it is necessary to connect a number of cells together to form a solar panel, also known as a photovoltaic module.
- The nominal output voltage of a solar panel is usually 12 Volts, and they may be used singly or wired together into an array.
- The number and size required is determined by the available light and the amount of energy required.



How Solar Panels Work?

- Photovoltaic cell converts sunlight into electric energy and this effect is known as photovoltaic effect.
- Solar cells essentially create electricity by converting photons of light into electrons.
- Solar cell producing direct current, or DC, this DC current is converted to alternating current, or AC by using inverter.

PROMSUN



Photovoltaic Effect

- Photovoltaic effect is generated photons hit a semi-conductor
- Material with a higher energy than the gap between its Valence andConduction bands.
- Free electrons move on one side
- (n-side) while holes move on the
- other side (p-side)
- A difference of potential is
- created
- between n-side and p-side
- allowing current through a load
- outside of the semi-conductor.