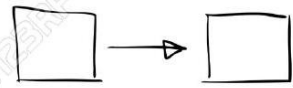


Thermodynamics

$U_i(n_i, P_i, V_i, \dots)$

 $U_f(n_f, P_f, V_f, \dots)$

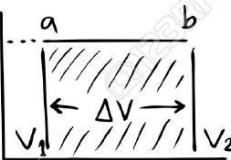
$W = -nRT \int_{V_i}^{V_f} \frac{dV}{V} = -nRT \ln\left(\frac{V_f}{V_i}\right)$
 $H = U + pV$
 $T(K) = T(^{\circ}C) + 273.15$
 $dH = dU + d(pV)$
 $dH = dU + p dV + V dp$

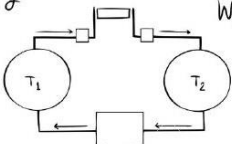
$C_p = (\Delta H / \Delta T)_p$
 $\Delta U = Q - W$
 $\Delta S = nRT \ln\left(\frac{V_f}{V_i}\right)$

$dU = dq + dw$
 $dH = dq - p dV + V dp$
 $C_p = \left(\frac{\partial H}{\partial T}\right)_p$
 $W = P \Delta U$
 $W = \int_{V_1}^{V_2} P dV$

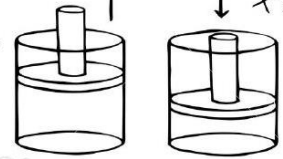
$H = U + P V$
 $\Delta H = q_p = C_p \times \Delta T$
 $C_v = (\Delta U / \Delta T)_v$
 $dS \geq \frac{dq}{T}$

$dU = m(u_2 - u_1) \Delta KE$
 $= \frac{1}{2} m (V_2^2 - V_1^2) \Delta PE$
 $= mg(z_2 - z_1)$


 $dS = \frac{dq_{rev}}{T}$
 $\Delta S = \int_i^f \frac{dq_{rev}}{T}$


 $\eta_{th} = \frac{W_{net}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$
 $W_b = \frac{P_2 V_2 - P_1 V_1}{1 - \gamma}$
 $dH = dq + V dp$
 $\Delta H = \Delta U + V \Delta p$

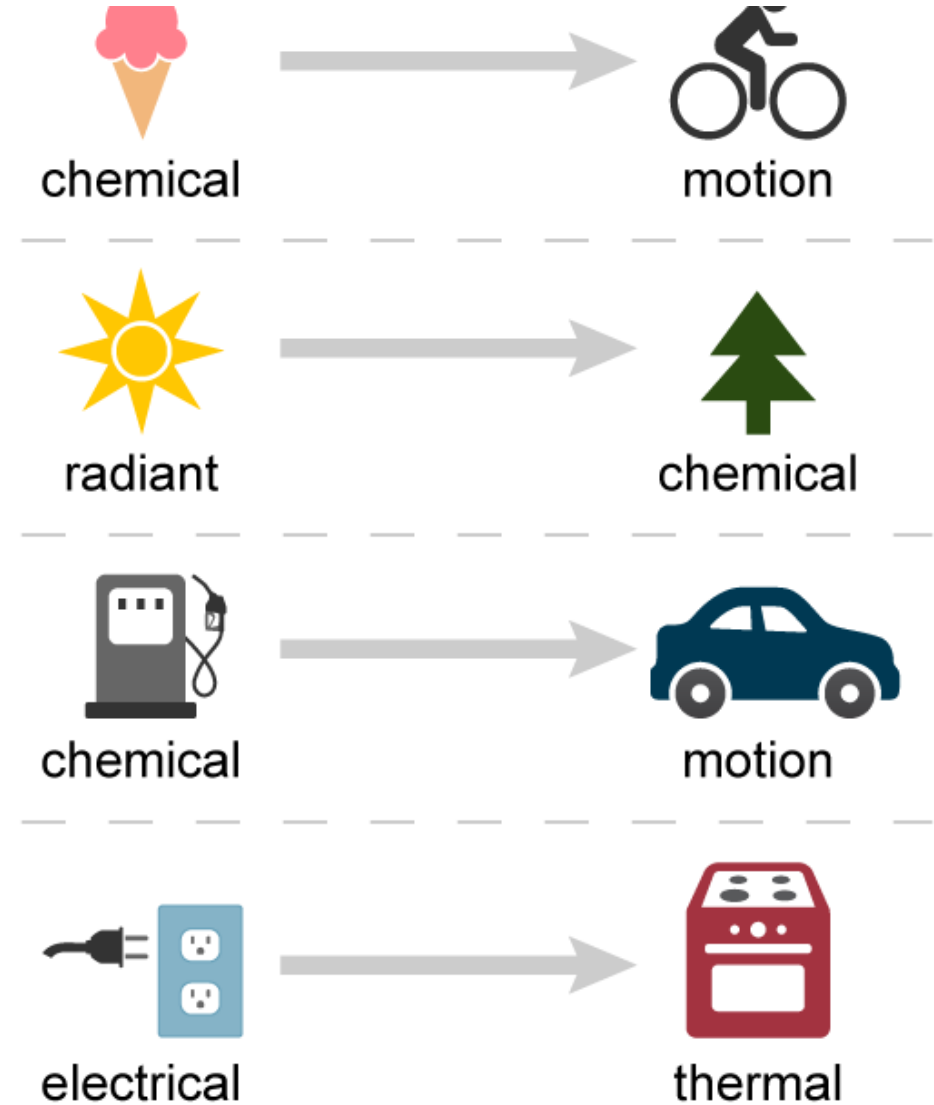
$dH = (dq)_p$
 $\Delta H = q_p$
 $T_R = \frac{T}{T_{cr}}$
 $dU = C_v dT$
 $\Delta U = q_v = C_v \times \Delta T$
 $\Delta U = U_f - U_i = q(\text{heat}) + w(\text{work})$


 $x = \frac{mg}{m_f + mg}$
 $\gamma_R = \frac{V_{cr}}{RT_{cr}}$

Thermodynamics

What is Thermodynamics?

- It is the science that relate energy (work and heat) to the change of system properties.

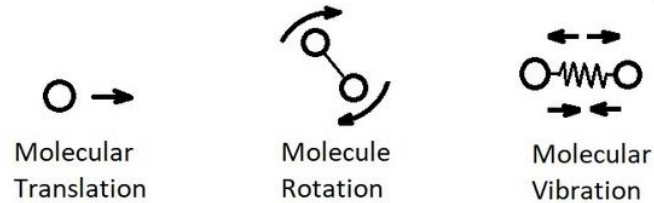


What is Internal Energy?

The internal energy is the energy contained within the system.

It consists of :

1. **Sensible component:** which accounts for the translational, rotational, and/or vibrational motion of the atoms/molecules.
2. **Latent component:** which relates to intermolecular forces influencing phase change between solid, liquid, and vapor states.
3. **Chemical component:** which accounts for energy stored in the chemical bonds between atoms.
4. **Nuclear component:** which relates to the strong bonds within the nucleus of the atom itself.

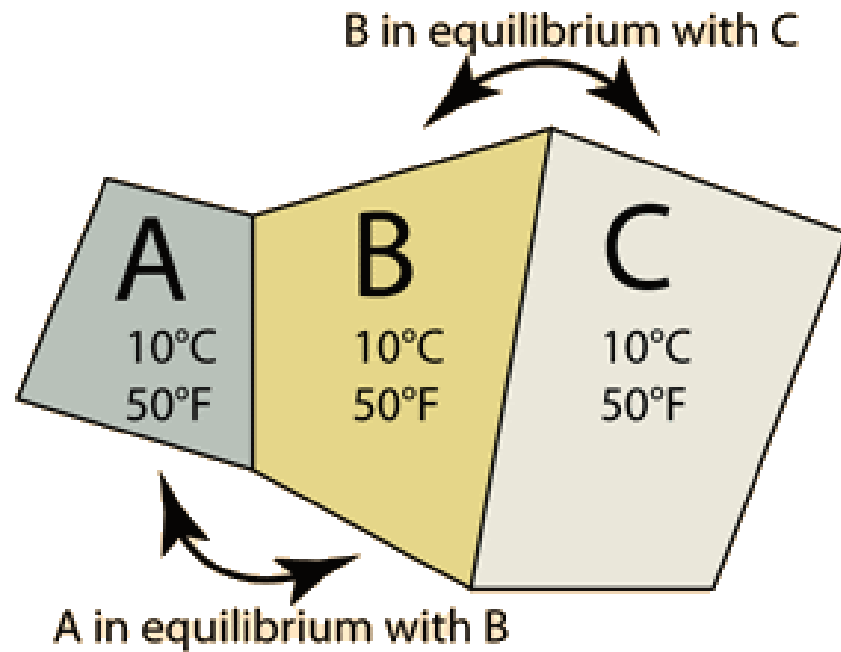


What is Enthalpy?



$$H = U + pV$$

What is the 0th law ?

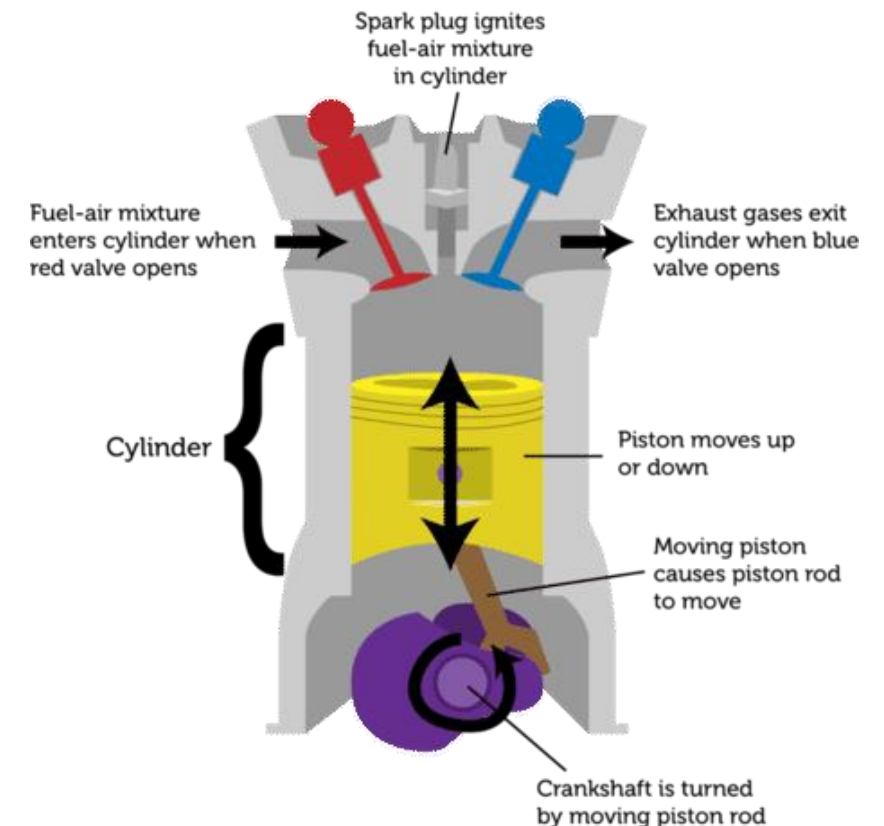


- **The zeroth law** says that when two objects are individually in thermal equilibrium with a third object, then they are also in equilibrium with each other.

What is the 1st law of thermodynamics?

- The first law of thermodynamics is a version of the law of conservation of energy.
- The First Law of Thermodynamics states that energy cannot be created or destroyed - only converted from one form of energy to another.
- The example is the **internal combustion engine**.
- The chemical energy (fuel air mixture) & the heat (ignition) are converted into mechanical work and some useless forms of energy (heat coming out).

Internal Combustion Engine



What is the equation of the 1st law of thermodynamics?

$$\Delta E_2 = Q_2 - W_2$$

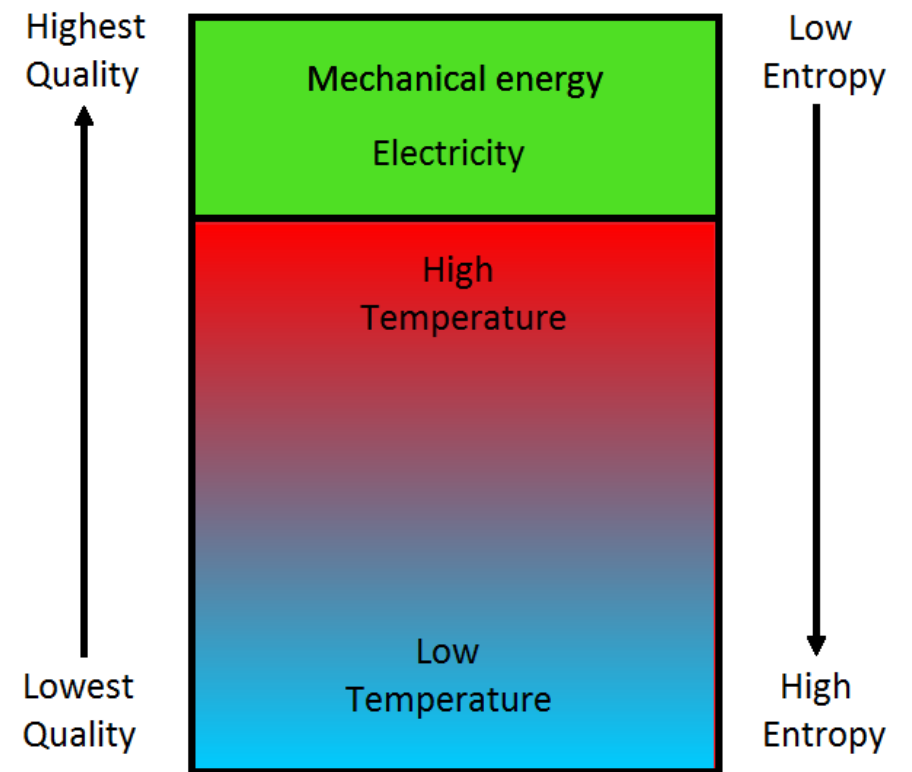
$$Q_2 = \Delta E_2 + W_2$$

$$Q_2 = m(u_2 + \frac{v_2^2}{2} + gz_2) - m(u_1 + \frac{v_1^2}{2} + gz_1) + W_2$$

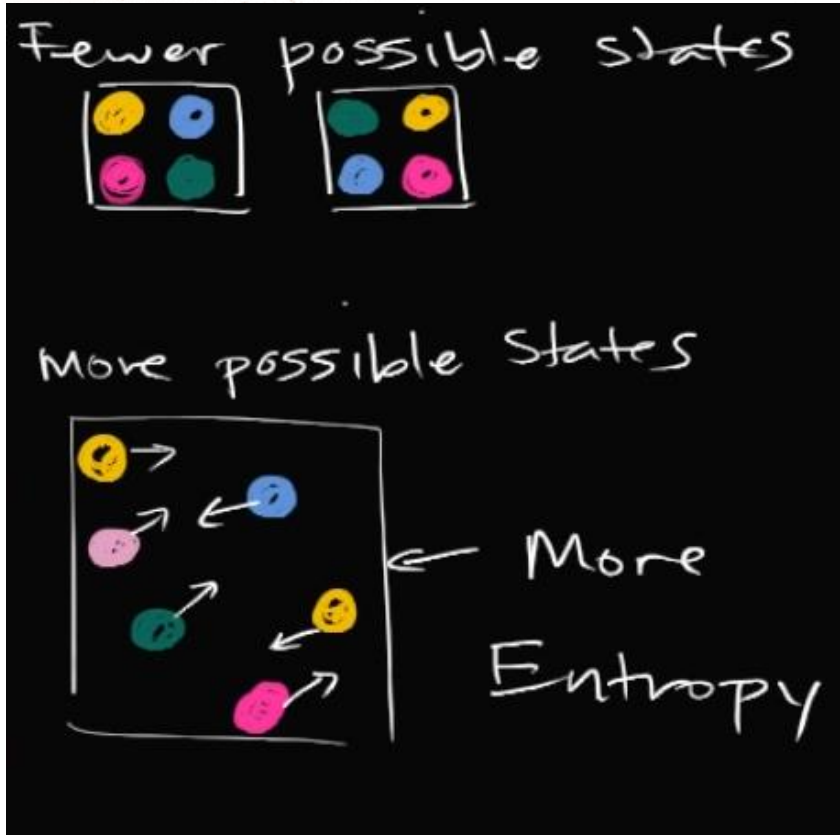
$$\dot{Q}_{cv} = \sum \dot{m}_e (h_e + \frac{v_e^2}{2} + gz_e) - \sum \dot{m}_i (h_i + \frac{v_i^2}{2} + gz_i) + \dot{W}_{cv}$$

What is the 2nd law of thermodynamics?

- The Second Law of Thermodynamics is about the **quality** of energy.
- It states that as energy is transferred or transformed, more and more of it is wasted.
- It's why engineers still can't make a perfectly efficient machine.
- It also states that the entropy of an isolated system is always increasing.
- The more entropy we generate, the less energy is leftover to do useful work.



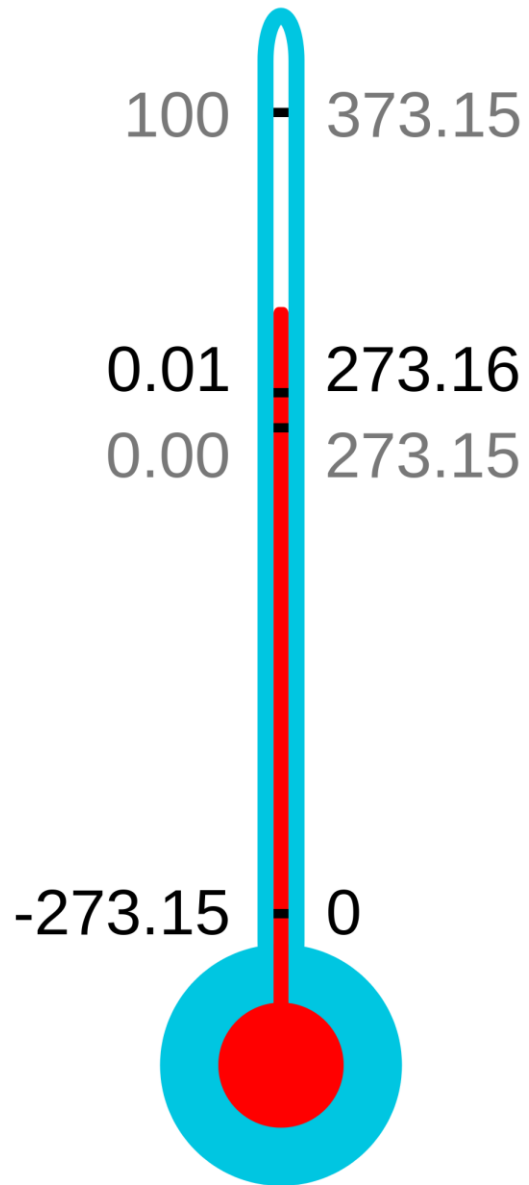
What is entropy?



- **Entropy** is the disorder of a system.
- The disorder relates to the number of possible states that a system can take on.

°C

K

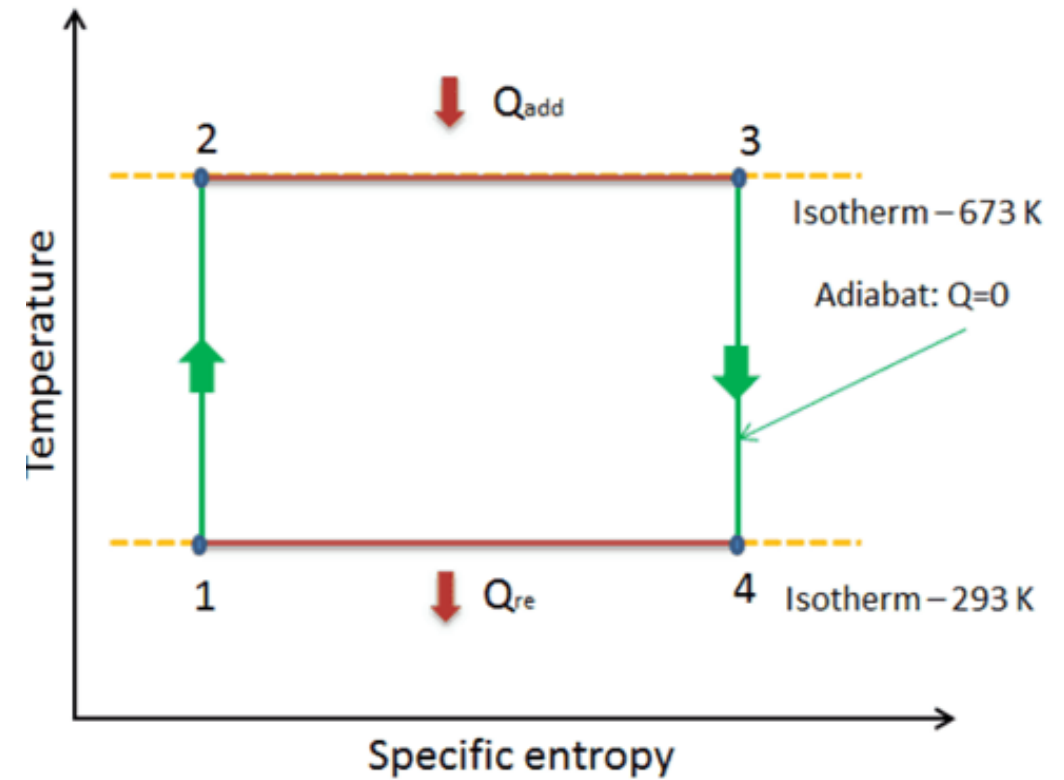


What is the 3rd law of thermodynamics?

- It is **impossible** to lower the temperature of **any system** to **absolute zero** in a finite number of steps.

Can you explain the Carnot cycle?

- **Carnot cycle** is a reversible cycle (consists entirely of reversible processes) and is the most efficient cycle.
- **Reversible cycles** cannot be achieved in practice because of the irreversibilities:
 - Friction.
 - Mixing of Two Fluids.
 - Heat Transfer.
 - Plastic Deformation of Solids.
 - Chemical Reactions.



What is the difference between the efficiencies in both laws?

First-law efficiency

Thermal efficiency is a measure of the performance of a heat engine.

Second-law efficiency :

- The ratio of the actual thermal efficiency to the Carnot efficiency under the same conditions.
 - **Carnot efficiency** is the highest efficiency a heat engine.
- For example, the maximum efficiency of a steam power plant operating between $T_H = 1000 \text{ K}$ and $T_L = 300 \text{ K}$ is 70%.
- While an actual efficiency of 40%.

$$\eta_{\text{th,rev}} = 1 - \frac{T_L}{T_H}$$

$$\eta_{\text{II}} = \frac{\eta_{\text{th}}}{\eta_{\text{th,rev}}}$$

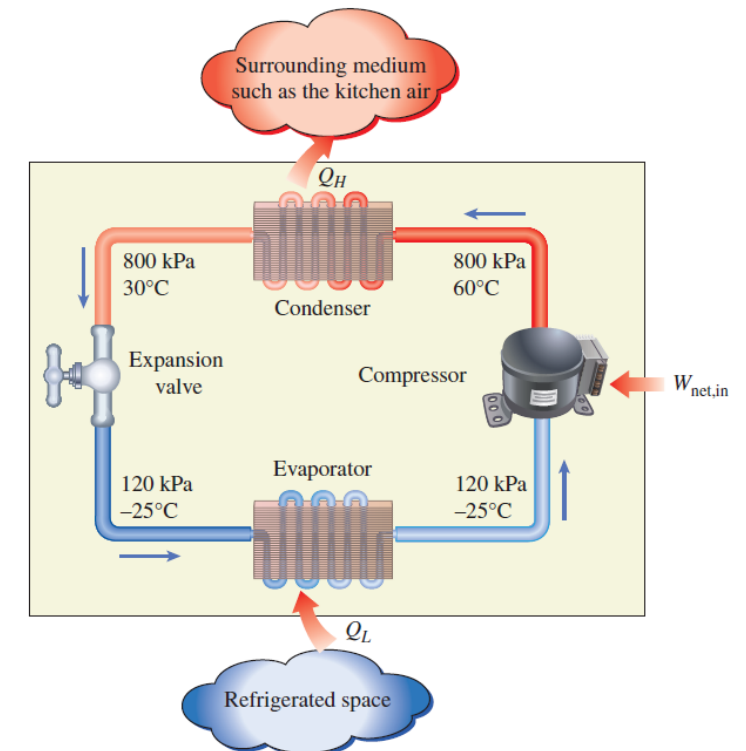
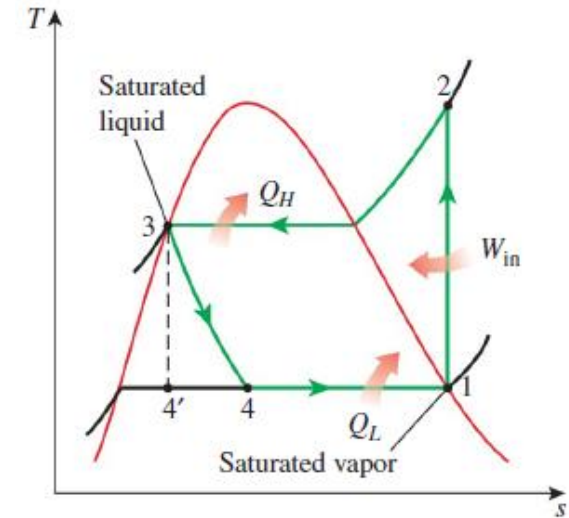
$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

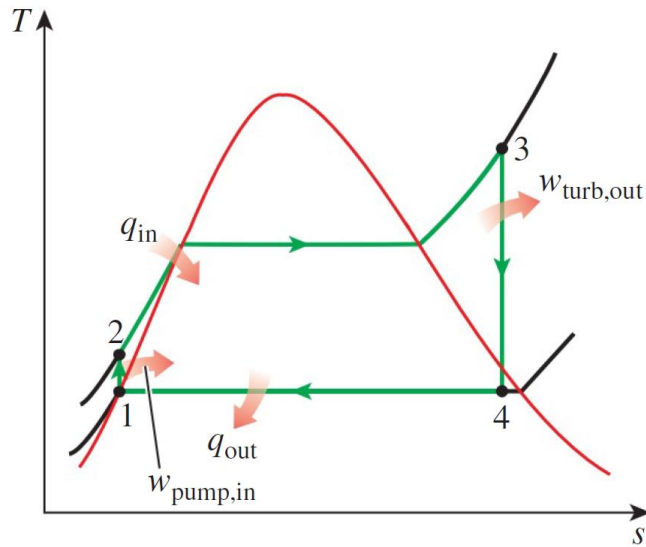
$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_{\text{in}}}$$

Draw & Explain the Refrigeration cycle.

A refrigerant, which is a substance moved repeatedly in these four components, should have some important characteristics such as low flammability, low toxicity, and low boiling point.

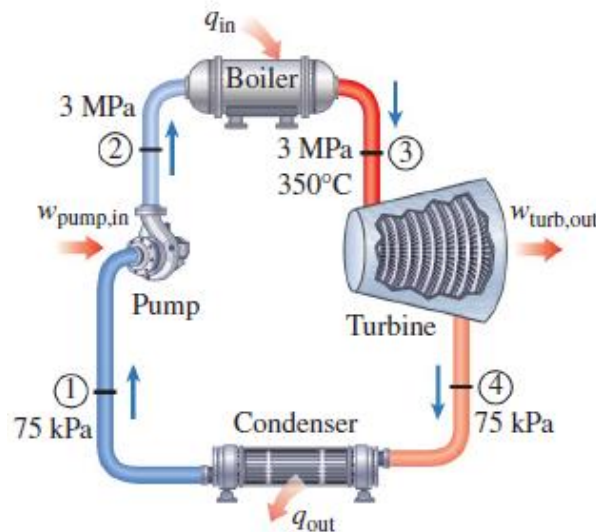
1. The evaporator is responsible to cool the refrigerated space. To do so, the refrigerant need to be a **cold mix of liquid and gas** in the inlet of the evaporator.
2. As the refrigerant moves through the evaporator coil, the refrigerant become a **cool gas** in the outlet of the evaporator.
3. The remaining stages are responsible to bring the refrigerant back to this desired state.
4. Then the compressor converts the cool gas/vapor into a **very hot and high-pressure vapor**.
5. The condenser is responsible for converting the refrigerant **into a hot and high-pressure liquid**.
6. The expansion device is responsible for converting the refrigerant into a **cold mix of liquid and gas**, which is our desired state in the evaporator.





Draw & Explain the Rankin cycle

- Water enters the pump at state 1 as saturated liquid and is compressed isentropically to the operating pressure of the boiler.
- The water temperature increases somewhat during this isentropic compression process due to a slight decrease in the specific volume of water. The vertical distance between states 1 and 2 on the T-s diagram is greatly exaggerated for clarity. (If water were truly incompressible, would there be a temperature change at all during this process?) Water enters the boiler as a compressed liquid at state 2 and leaves as a superheated vapor at state 3.
- The boiler is basically a large heat exchanger where the heat is transferred to the water essentially at constant pressure.
- The superheated vapor at state 3 enters the turbine, where it expands isentropically and produces work by rotating the shaft connected to an electric generator. The pressure and the temperature of steam drop during this process to the values at state 4, where steam enters the condenser. At this state, steam is usually a saturated liquid–vapor mixture with a high quality. Steam is condensed at constant pressure in the condenser, which is basically a large heat exchanger, by rejecting heat to a cooling medium such as a lake, a river, or the atmosphere. Steam leaves the condenser as saturated liquid and enters the pump, completing the cycle.
- These plants can be (a) fossil-fueled, (b) nuclear-fueled, (c) solar thermal, and (d) geothermal.



Draw & Explain the Brayton Cycle

Gas turbines usually operate on an *open cycle*.

1. Fresh air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised.
 2. The high-pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure.
 3. The resulting high-temperature gases then enter the turbine, where they expand to the atmospheric pressure while producing power. The exhaust gases leaving the turbine are thrown out.
- The two major application areas of gas-turbine engines are aircraft propulsion and electric power generation.

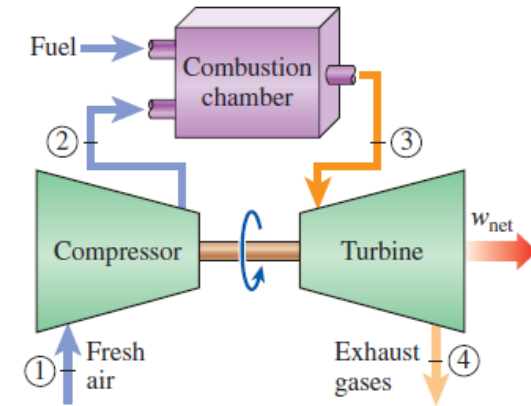
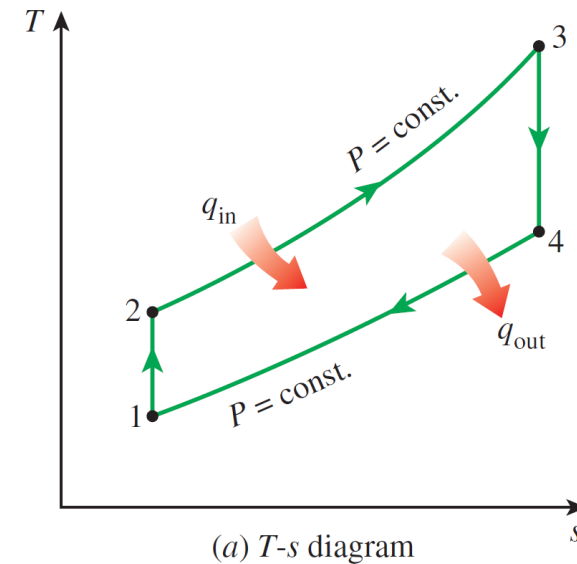
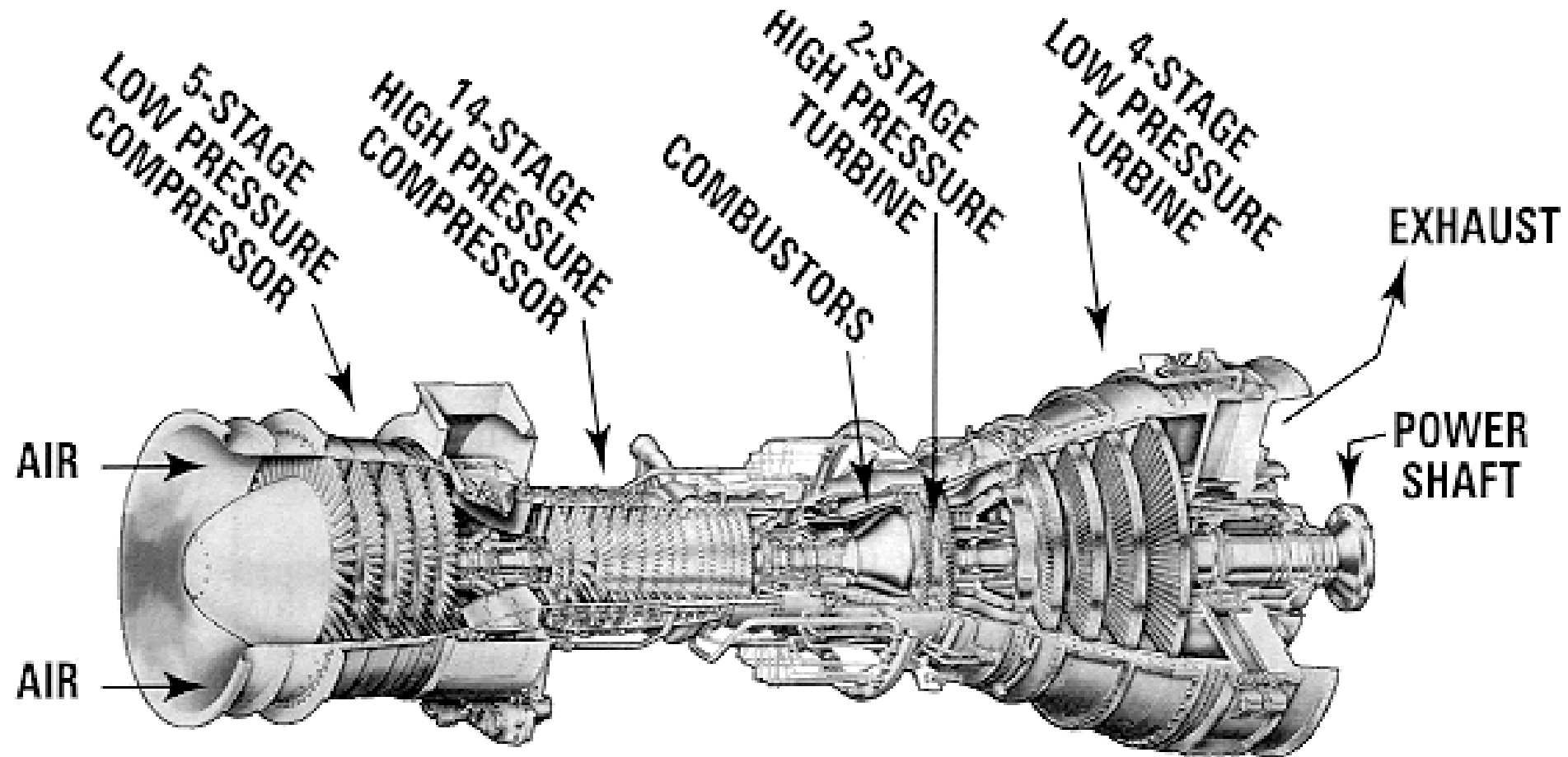


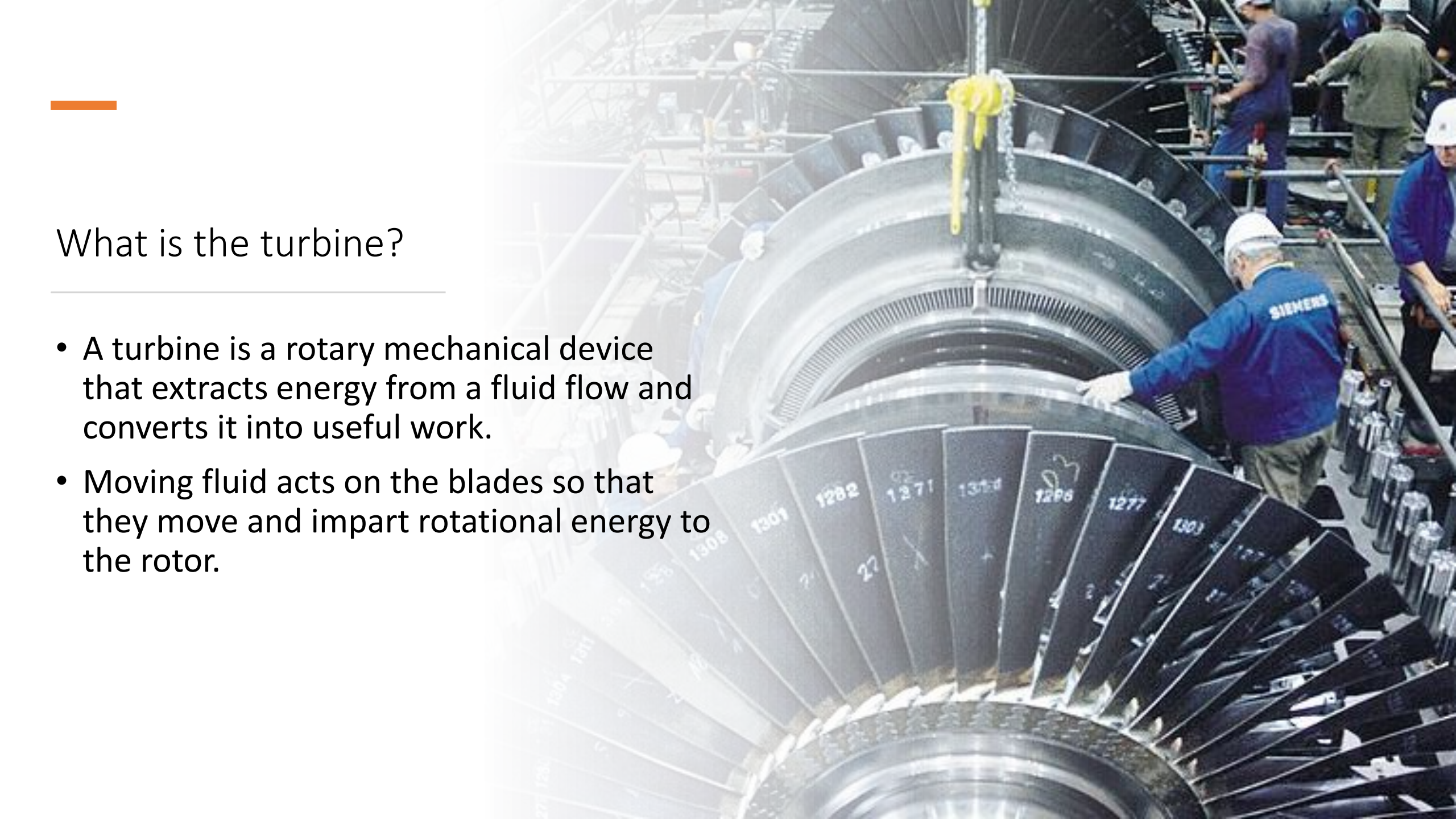
FIGURE 9-29

An open-cycle gas-turbine engine.



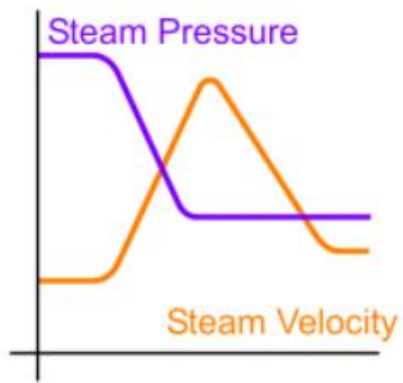
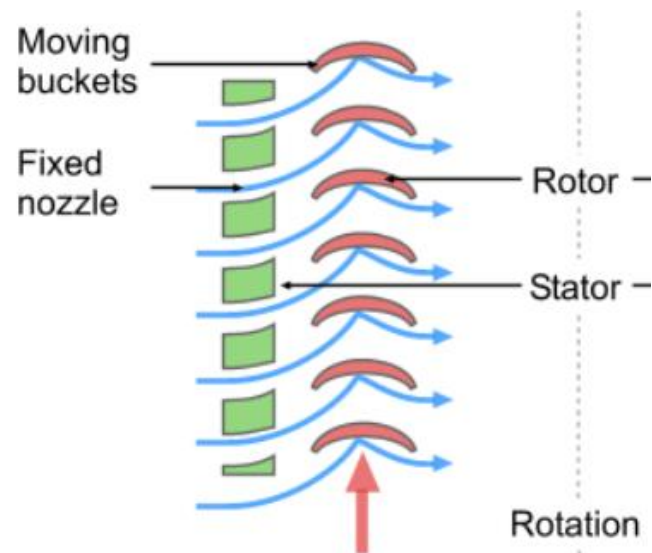
What are the stages of jet engine?



The background image shows a large-scale industrial manufacturing environment. In the foreground, a massive, circular turbine component is being assembled. It features numerous curved blades or segments, some of which are labeled with numbers like 1282, 1271, 1301, 1298, 1277, and 1303. A worker in a blue jacket with 'SIEMENS' written on the back and a white hard hat is visible, working on the turbine. Other workers in similar attire are seen in the background, and a yellow crane hook is positioned above the turbine. The scene is brightly lit, emphasizing the metallic surfaces and the scale of the machinery.

What is the turbine?

- A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work.
- Moving fluid acts on the blades so that they move and impart rotational energy to the rotor.

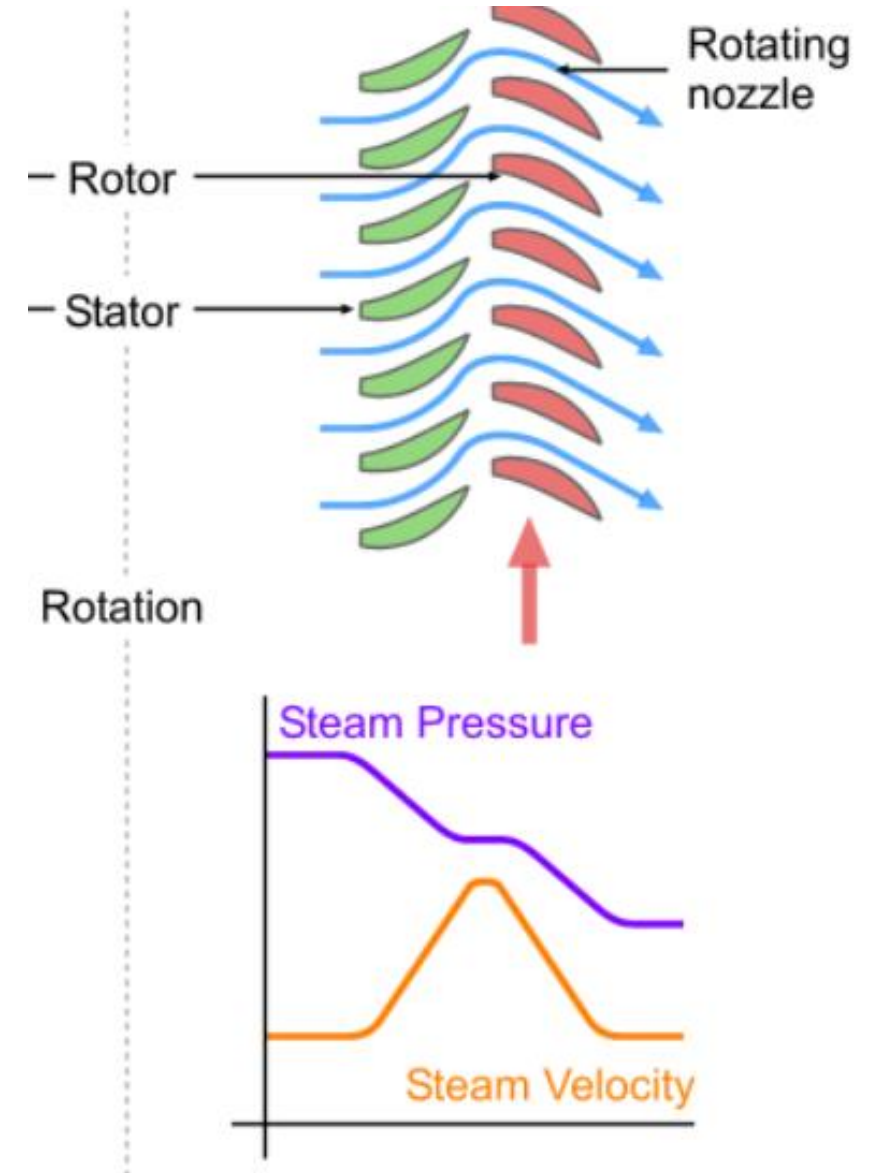


Impulse Principle

- **Impulse turbines** change the direction of flow of a high velocity fluid or gas jet. The resulting impulse spins the turbine and leaves the fluid flow with diminished kinetic energy.
- There is no pressure change of the fluid or gas in the turbine blades (the moving blades), as in the case of a steam or gas turbine, all the pressure drop takes place in the stationary blades (the nozzles). Before reaching the turbine, the fluid's pressure head is changed to velocity head by accelerating the fluid with a nozzle.

Reaction Principle

- **Reaction turbines** develop torque by reacting to the gas or fluid's pressure or mass. The pressure of the gas or fluid changes as it passes through the turbine rotor blades.
- Most steam turbines use this concept.
- Reaction turbines are better suited to higher flow velocities or applications where the fluid head (upstream pressure) is low.

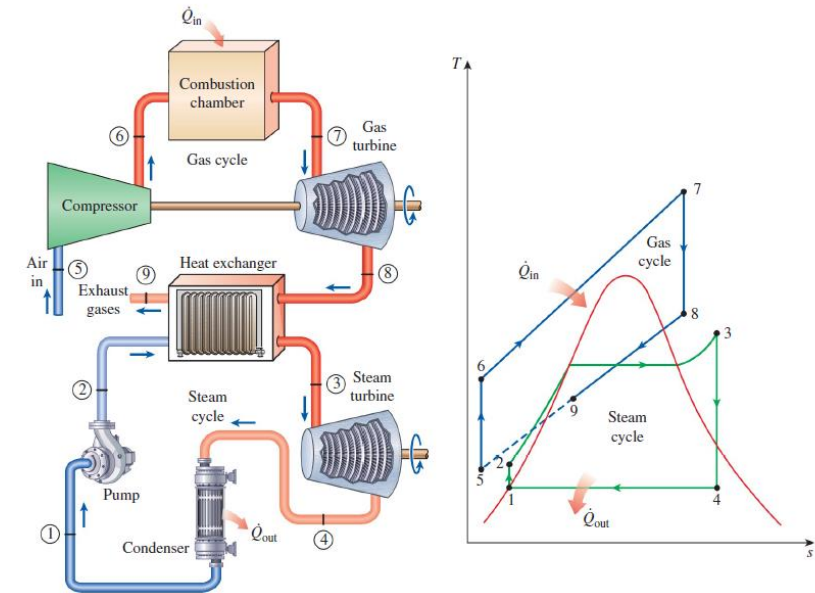


What is the difference between the steam turbine and gas turbine?

In term of	steam turbine	gas turbine
Working Fluid	high pressure steam	air or some other gas
Work Output	delivers torque only.	Deliver either torque or thrust.
The Space Required	More, requires boilers and heat exchangers, which should be connected externally. executing one step of the Rankine cycle	Less, combined device of compressor, combustion chamber, and turbine executing a cyclic operation executes the whole Brayton cycle.
The Efficiency	Lower, lower operating temperatures. steam turbines ~550 OC	Higher, higher operating temperatures. Gas turbines ~1500 OC

The combined cycle

- The combined cycle of greatest interest is the gas-turbine (Brayton) cycle topping a steam turbine (Rankine) cycle, which has a higher thermal efficiency than either of the cycles executed individually.
- The use of higher temperatures in gas turbines is made possible by developments in cooling the turbine blades and coating the blades with high-temperature-resistant materials such as ceramics.
- In this cycle, energy is recovered from the exhaust gases by transferring it to the steam in a heat exchanger that serves as the boiler. In general, more than one gas turbine is needed to supply sufficient heat to the steam.





Define the combustion and what is the oxygen's role in combustion?

- Combustion is a chemical reaction during which a fuel is **oxidized**, and a large quantity of energy is release.
- The **oxidizer** most often used in combustion processes is air, for obvious reasons—it is free and readily available.
- We should also mention that bringing a fuel into intimate contact with oxygen is not sufficient to start a combustion process.
- The fuel must be brought above its ignition temperature to start the combustion.

What is fuel?

- Any material that can be burned to release thermal energy is called a **fuel**.
- Most familiar fuels consist primarily of hydrogen and carbon. They are called hydrocarbon fuels and are denoted by the general formula C_nH_m .
- Hydrocarbon fuels exist in all phases, some examples being coal, gasoline, and natural gas.



Differentiate between dry and atmospheric air?

- Air in the atmosphere normally contains some water vapor (or moisture) and is referred to as **atmospheric air**.
- By contrast, air that contains no water vapor is called **dry air**.
- It is often convenient to treat air as a mixture of water vapor and dry air since the composition of dry air remains relatively constant, but the amount of water vapor changes as a result of condensation and evaporation from oceans, lakes, rivers, showers, and even the human body.
- Although the amount of water vapor in the air is small, it plays a major role in human comfort.

$$\text{Air} = \text{Water vapor} + \text{Dry Air}$$

(changing due to condensation & evaporation) (Relatively constant)

Important Parameters

- **Absolute or Specific humidity** specify directly the mass of water vapor present in a unit mass of **dry air**.
- Consider 1 kg of dry air. By definition, dry air contains no water vapor, and thus its specific humidity is zero. let us add some water vapor to this dry air. The specific humidity will increase. As more vapor or moisture is added, the specific humidity will keep increasing until the air can hold no more moisture. At this point, the air is said to be saturated with moisture, and it is called **saturated air**. Any moisture introduced into saturated air will condense.

$$\omega = \frac{m_v}{m_a}$$

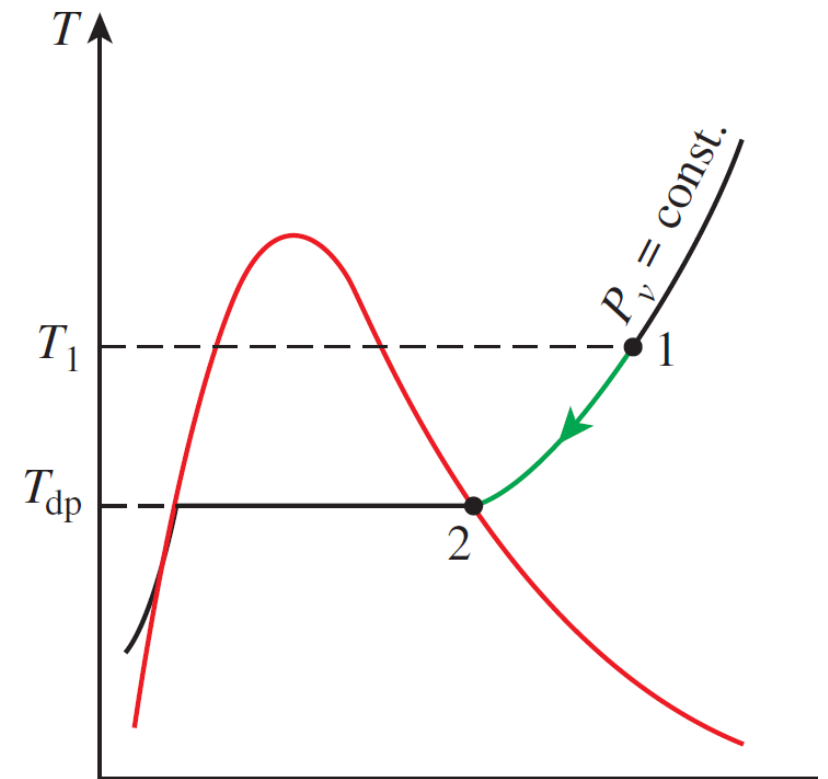
Important Parameters

- The comfort level depends more on the amount of moisture the air holds (m_v) relative to the maximum amount of moisture the air can hold at the same temperature (m_g). The ratio of these two quantities is called the **relative humidity**

$$\phi = \frac{m_v}{m_g}$$

Dew-point Temperature

- If you live in a humid area, you are probably used to waking up most **summer mornings** and finding the grass wet. You know it did not rain the night before. So what happened? Well, the excess moisture in the air simply condensed on the **cool surfaces**, forming what we call **dew**. In summer, a considerable amount of water vaporizes during the day. As the temperature falls during the night, so does the “moisture capacity” of air, which is the maximum amount of moisture air can hold. (What happens to the relative humidity during this process?) After a while, the moisture capacity of air equals its moisture content. At this point, air is saturated, and its relative humidity is 100 percent. Any further drop in temperature results in the condensation of some of the moisture, and this is the beginning of dew formation.
- The **dew-point temperature T_{dp}** is defined as the temperature at which condensation begins when the air is cooled at constant pressure.



Air Conditioning Processes

- Notice that simple heating and cooling processes appear as horizontal lines on this chart since the moisture content of the air remains constant (w constant) during these processes.
- **Air is commonly heated and humidified in winter and cooled and dehumidified in summer.**

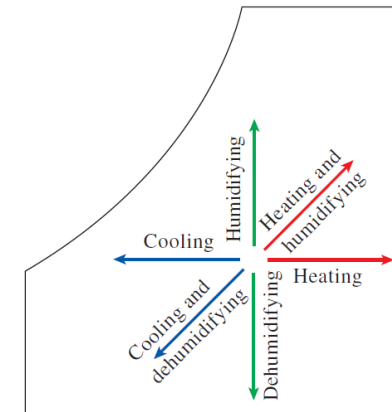
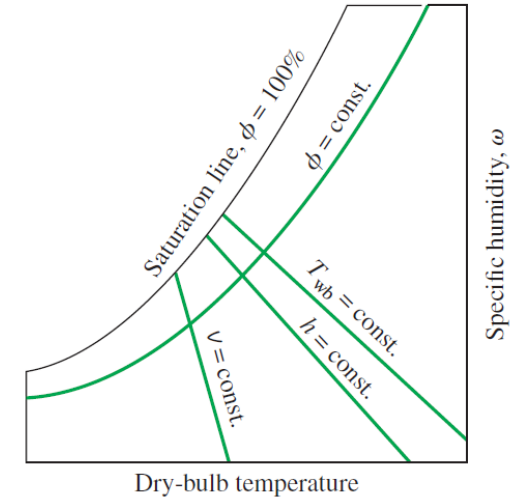
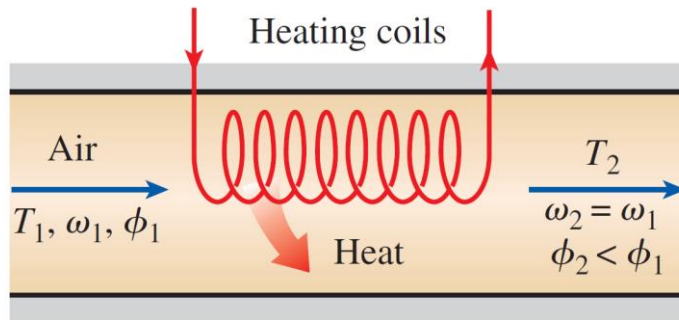


FIGURE 14-19

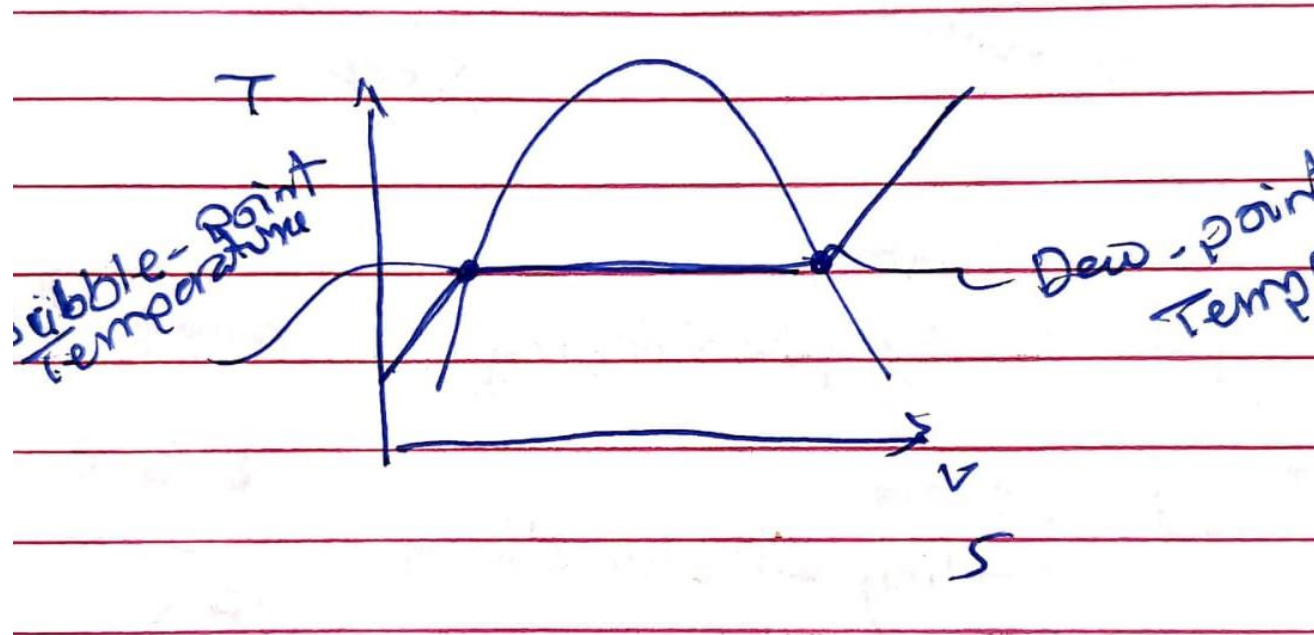
Various air-conditioning processes.

Simple Heating and Cooling (w constant)



- Notice that the relative humidity of air decreases during a heating process even if the specific humidity v remains constant. This is because the relative humidity is the ratio of the moisture content to the moisture capacity of air at the same temperature, and moisture capacity increases with temperature.
- A cooling process at constant specific humidity is similar to the heating process discussed above, except the dry-bulb temperature decreases and the relative humidity increases during such a process

Identify the bubble point



- In thermodynamics, the bubble point is the temperature (at a given pressure) where the first bubble of vapor is formed when heating a liquid.

Venturi Effect

