Thermal & Statistical Physics

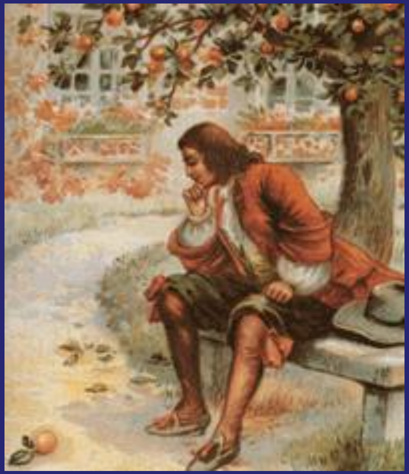
PHYS 343

Dr.Salwa Alsaleh

Salwams@ksu.edu.sa

fac.ksu.edu.sa/salwams

Lecture 12



Heat Capacity
Heat Engines
Entropy
2nd Law
3rd Law

Heat capacity

- A body has a capacity for heat. The smaller the temperature change in a body caused by the transfer of a given quantity of heat, the greater its capacity.

- A heat capacity: $$C \equiv \frac{dQ}{dT}$$

  - a process-dependent quantity rather than a state function.

- Two heat capacities, C_V and C_P, are in common use for homogeneous fluids; both as state functions, defined unambiguously in relation to other state functions.

Heat capacities at …

- At constant volume

$$C_V = \left(\frac{\partial E}{\partial T}\right)_V$$

$$\Delta E = \int_{T_1}^{T_2} C_V \, dT \quad (const\ v)$$

- C_V is a state function and is independent of the process.

- At constant pressure

$$C_P \equiv \left(\frac{\partial H}{\partial T}\right)_P$$

$$\Delta H = \int_{T_1}^{T_2} C_P dT \quad (const\ P)$$

- C_P is a state function and is independent of the process.

Specific Heat Capacities…

$$Q = n\,c\,\Delta T$$

c : **molar specific heat capacity** *in units of J/(mol·K)*

n : *number of moles*

$$\Delta T = T_f - T_i$$

$$Q = \Delta E + W$$

$$Q_{\text{constant pressure}} = \frac{3}{2} nR(T_f - T_i) + nR(T_f - T_i) = \frac{5}{2} nR(T_f - T_i)$$

$$Q_{\text{constant volume}} = \frac{3}{2} nR(T_f - T_i) + 0$$

Specific Heat Capacities

The molar specific heat capacities can now be determined

Constant pressure for a monatomic ideal gas

$$C_P = \frac{Q_{\text{constant pressure}}}{n(T_f - T_i)} = \frac{5}{2}R$$

Constant volume for a monatomic ideal gas

$$C_V = \frac{Q_{\text{constant volume}}}{n(T_f - T_i)} = \frac{3}{2}R$$

The ratio specific heats isγ of the

Monatomic ideal gas

$$\gamma = \frac{C_P}{C_V} = \frac{\frac{5}{2}R}{\frac{3}{2}R} = \frac{5}{3}$$

Exemple : Calculate the internal-energy and enthalpy changes that occur when air is changed from an initial state of 40°F and 10 atm, where its molar volume is 36.49 ft^3/lb-mole, to a final state of 140°F and 1 atm. Assume for air that PV/T is constant and that C_V = 5 and C_P = 7 Btu/lb-mol.F.

Independent of paths! ⟶ Two-step process:

(1) cooled at constant volume to the final pressure;
(2) heated at constant pressure to the final temperature.

$$T_1 = 40 + 459.67 = 499.67\ R$$

$$T_2 = 140 + 459.67 = 599.67\ R$$

Constant volume

$$T' = T_1 \frac{P_1}{P_2} = 49.97\ R$$

$$\Delta U = C_V \Delta T = -2248.5\ Btu$$

$$\Delta H = \Delta U + \Delta(PV) = -3141.6\ Btu$$

Constant pressure

$$V_2 = V_1 \frac{P_1 T_2}{P_2 T_1} = 437.93\ ft^3$$

$$\Delta H = C_P \Delta T = 3847.9\ Btu$$

$$\Delta U = \Delta H - P\Delta V = 2756.2\ Btu$$

Intermediate state

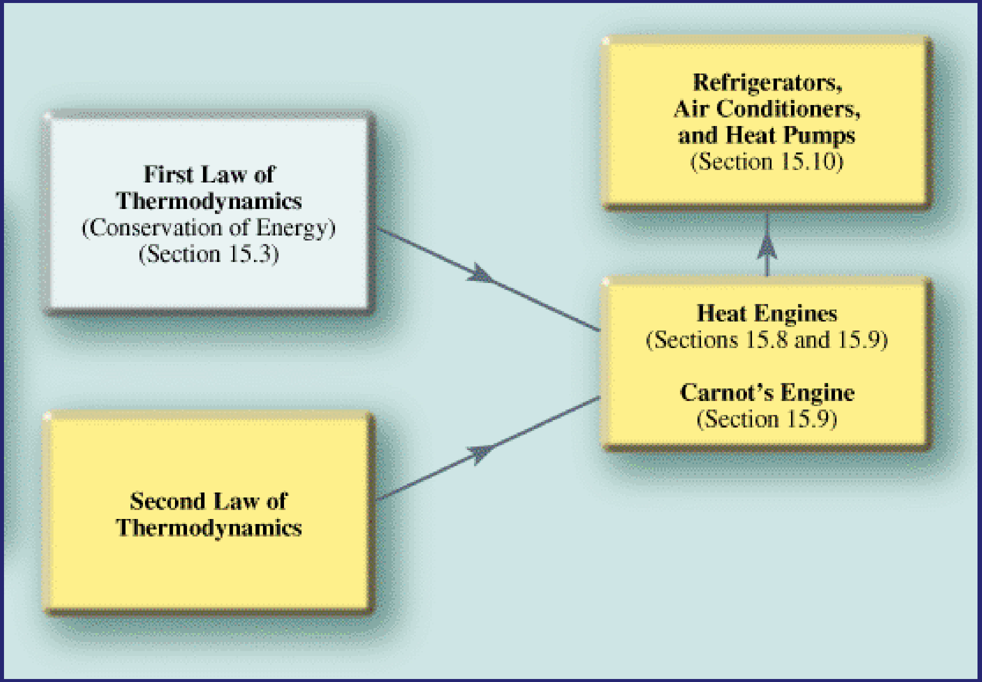
$$\Delta H = \Delta H_1 + \Delta H_2 = 507.7\ Btu$$

$$\Delta U = \Delta U_1 + \Delta U_2 = 706.3\ Btu$$

Second Law of Thermodynamic

THE SECOND LAW OF THERMODYNAMICS: THE HEAT FLOW STATEMENT:

Heat flows spontaneously from a substance at a higher temperature to a substance at a lower temperature and does not flow spontaneously in the reverse direction.

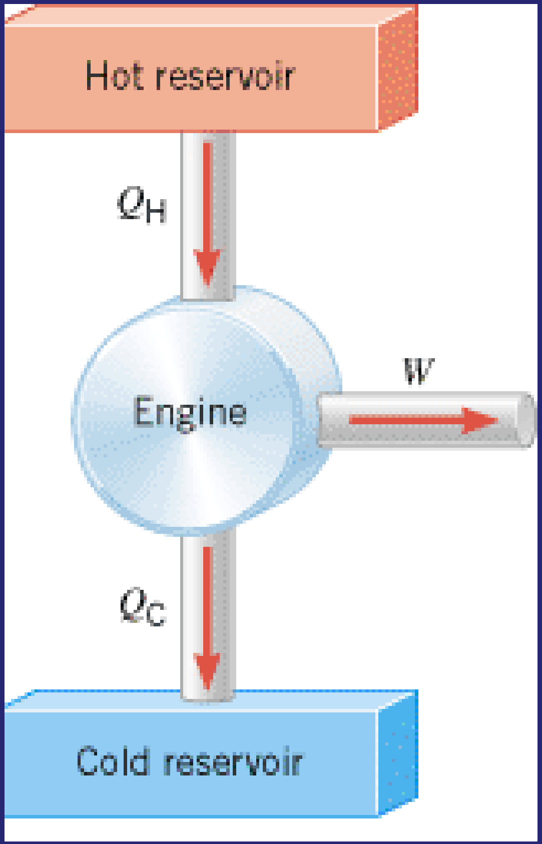


Heat Engine

- A device that is able to convert thermal energy to mechanical energy.
- An internal combustion engine.

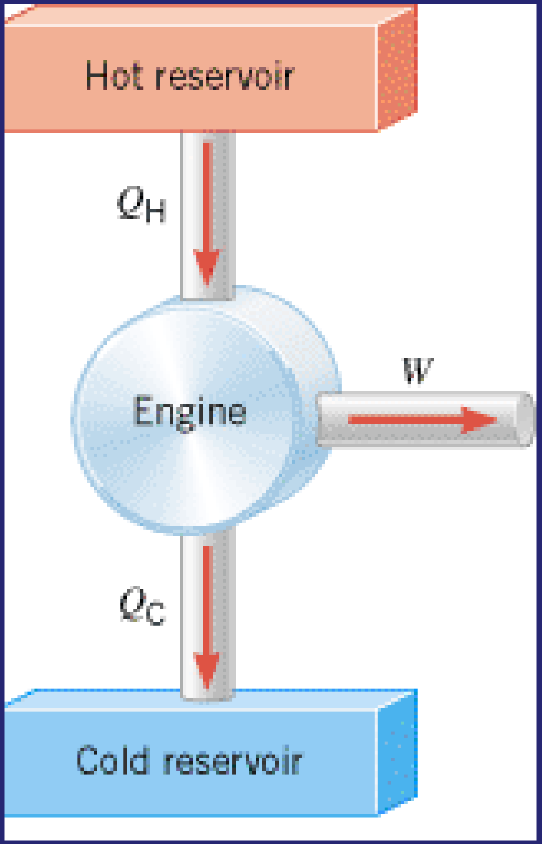
Requirements

- ***High temperature source***
- ***Low temperature sink***



Heat Engines

Uses heat to perform work
- Hot reservoir provides heat
- Part of the heat is used to do work
- remaining heat is rejected to a cold reservoir



Efficiency = Work done / input heat = W / Q_H

Should obey the principle of conservation of energy:

$$Q_H = W + Q_C$$
$$e_{ff} = w / Q_H$$
$$e_{ff} = (Q_H - Q_C) / Q_H$$

Efficiency

$$Eff = 1 - \frac{Q_C}{Q_H}$$

The Carnot Cycle

The Carnot Cycle ….

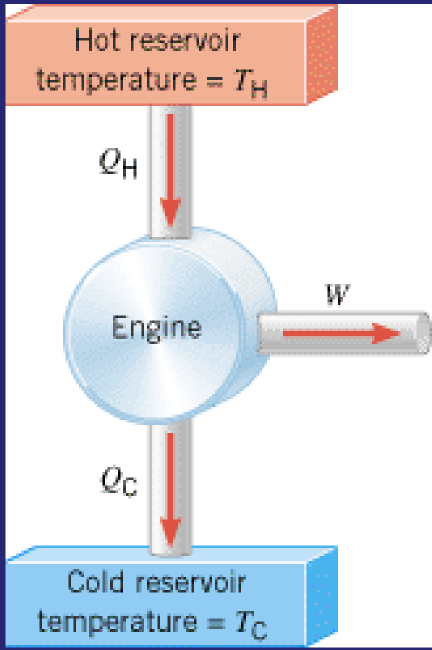
- The most efficient type of heat engine
- Developed by Sadi Carnot
- Piston works between heat source and heat sink
- Four processes
- It is only theoretical…it does not exist.

Carnot's Principle

Sadi Carnot (1796-1832)

A reversible process is one in which both the system and its environment can be returned to exactly the states they were in before the process occurred.

No irreversible engine operating between two reservoirs at constant temperatures can have a greater efficiency than a reversible engine operating between the same temperatures. Furthermore, all reversible engines operating between the same temperatures have the same efficiency.



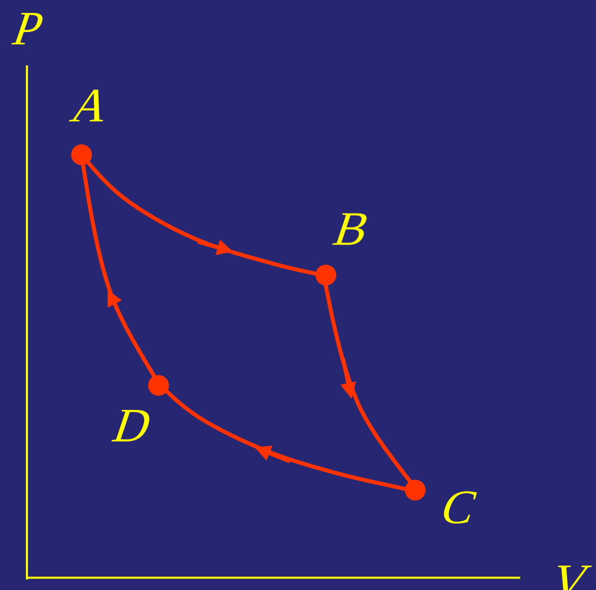
$$\text{Efficiency of a Carnot engine} = e_{\text{Carnot}} = 1 - \frac{T_C}{T_H}$$

The Carnot Cycle….

The Four Processes

- Isothermal expansion
- Adiabatic expansion
- Isothermal compression
- Adiabatic compression

The Carnot Cycle



AB : reversible isothermal at temperature T_1

BC: reversible adiabatic

CD : reversible isothermal at temperature $T_2 < T_1$

DA : reversible adiabatic

$$\Delta U_{ABCDA} = 0 \quad \Rightarrow \quad q_{AB} + q_{CD} = -w > 0$$

(the system does work)

Efficiency of Carnot engine:

$$\eta = \frac{|w|}{q_{AB}} = 1 - \frac{|q_{CD}|}{q_{AB}}$$

$$\eta = 1 - \frac{T_2}{T_1} < 1 \quad (\text{unless } \ T_2 = 0)$$

One can never utilize all the thermal energy given to the engine by converting it into mechanical work.

Efficiency of Carnot engine

$$\eta = 1 - \frac{T_2}{T_1} < 1 \quad (\text{unless} \;\; T_2 = 0)$$

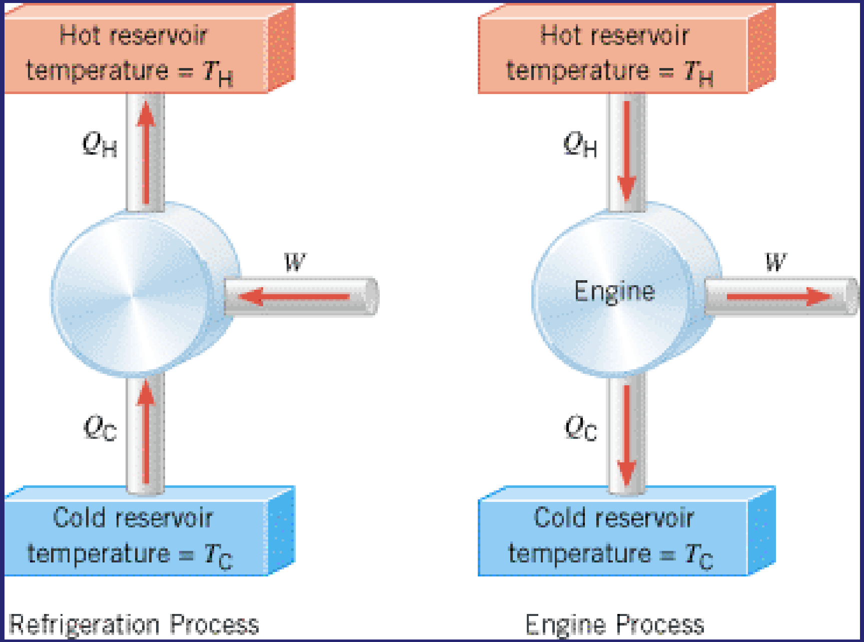
The Carnot Cycle….

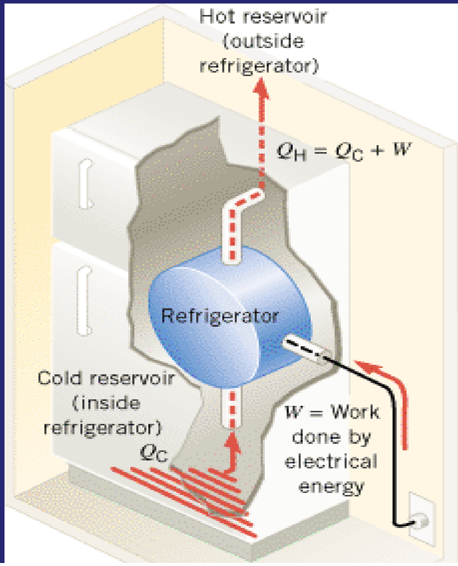
- Takes in heat from heat reservoir without changing temperature
- Does work on its environment
- Drops heat into heat sink
- The environment does work on it
- This is a cyclic process

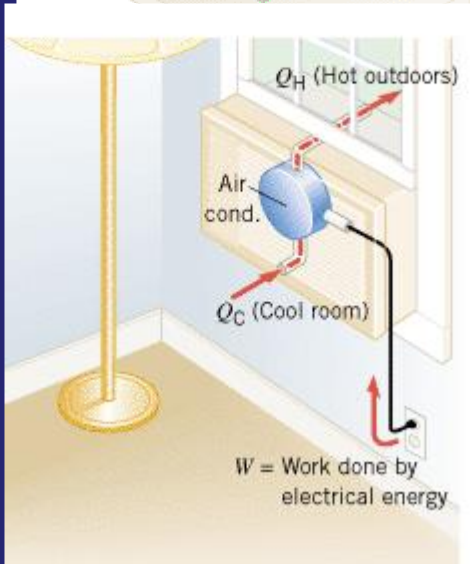
The Carnot Cycle ….

- Q_H = heat taken in from heat source
- Q_c = heat removed to heat sink
- W = Work done
- T_H = temperature of heat source
- T_C = temperature of heat sink

Refrigerators, Air conditioners and Heat Pumps



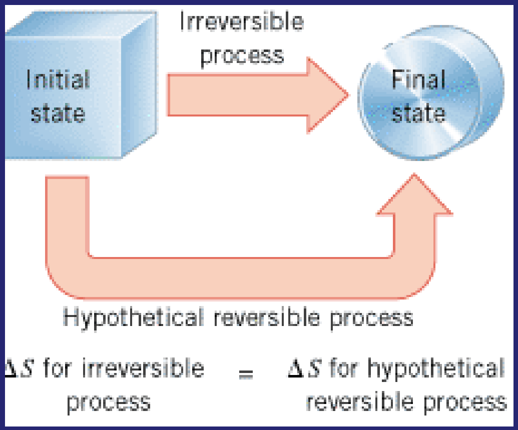




Refrigerator or air conditioner Coefficient of performance $= \frac{Q_C}{W}$

Entropy

In general, irreversible processes cause us to lose some, but not necessarily all, of the ability to perform work. This partial loss can be expressed in terms of a concept called ***entropy.***



To introduce the idea of entropy we recall the relation $Q_C/Q_H = T_C/T_H$ that applies to a Carnot engine. This equation can be rearranged as $Q_C/T_C = Q_H/T_H$, which focuses attention on the heat Q divided by the Kelvin temperature T. The quantity Q/T is called the change in the entropy ΔS:

$$\Delta S = \left(\frac{Q}{T}\right)_R$$

Change in entropy of Carnot's engine

$$\Delta S_C + \Delta S_H = \frac{Q_C}{T_C} - \frac{Q_H}{T_H} = 0$$

Reversible process does not alter the total entropy of the universe (2^{nd} Law in terms of entropy).

$\Delta S_{universe} = 0$

Entropy : Degree of disorder

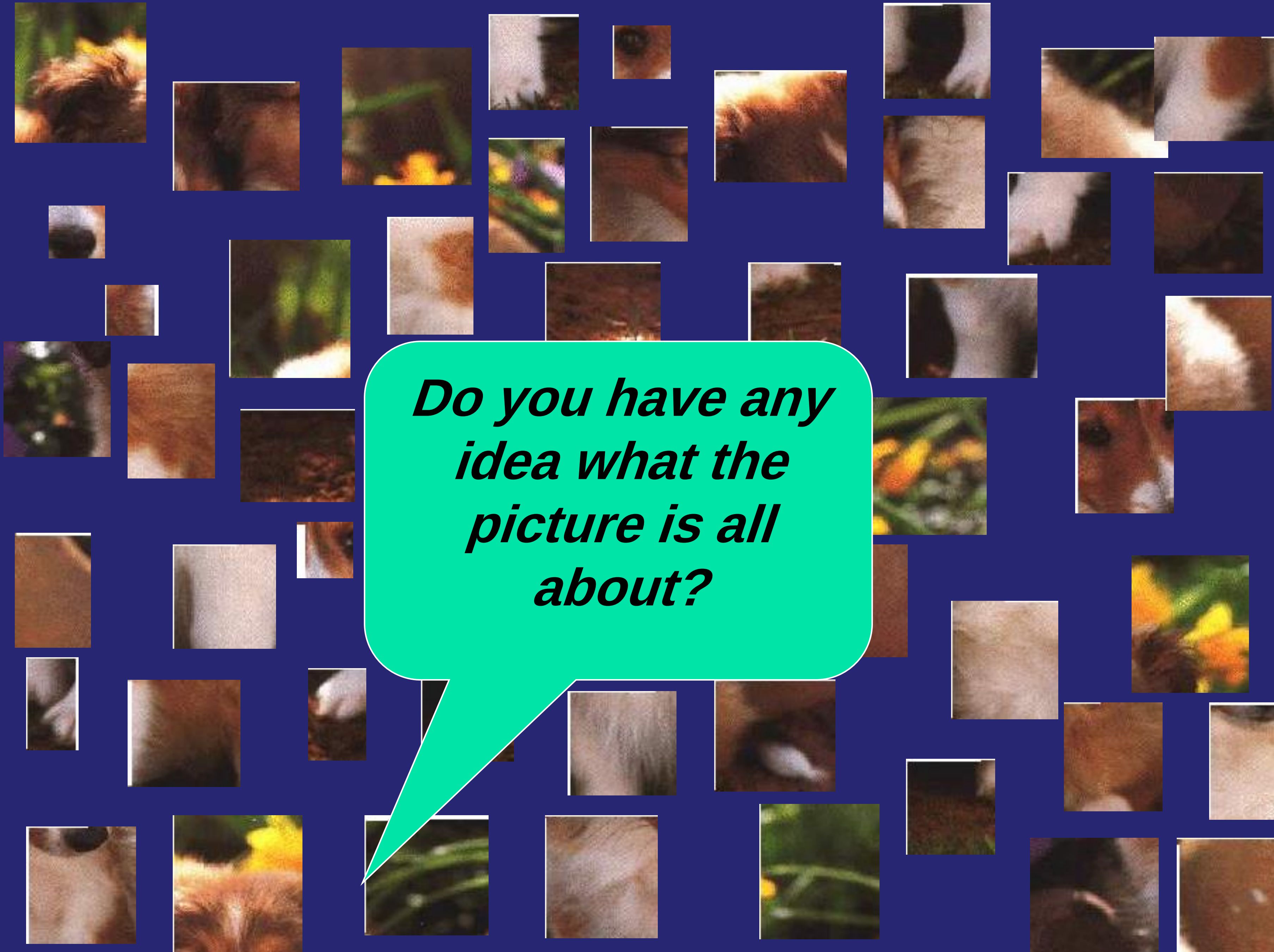
Entropy and Arrow of time

Third Law of Thermodynamics

THE SECOND LAW OF THERMODYNAMICS STATED IN TERMS OF ENTROPY

The total entropy of the universe does not change when a reversible process occurs

THE THIRD LAW OF THERMODYNAMICS It is not possible to lower the temperature of any system to absolute zero (T = 0 K) in a finite number of steps.


Do you have any idea what the picture is all about?