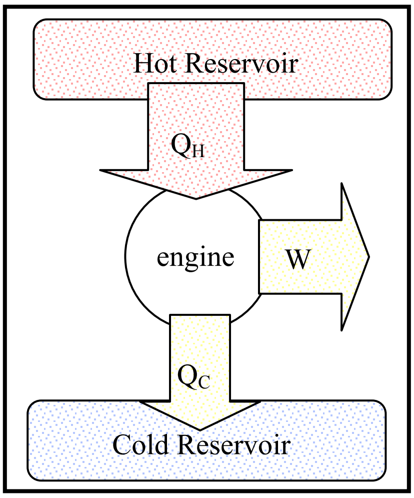
Workshop Tutorials for Physics

Solutions to TR6: **Heat Engines**

A. Qualitative Questions:

1. A car engine is a type of heat engine.

a. See diagram opposite.



b. The hot reservoir is the cylinder chamber where ignition occurs. The transfer of energy Q_H is from the combustion of the fuel. The cold reservoir is the water that circulates through the engine and loses the heat Q_C through the radiator eventually. The work done, W, is the work done in pushing the piston up, which turns the crankshaft.

c. The cyclic thermodynamic process occurs in the engine cylinders of the car.

d. The working substance of the engine is the fuel and air mix which is compressed and expands when ignited.

2. With the cost of fuel constantly increasing, it is important that engines be as efficient as possible.

a. In an ideal engine the efficiency depends on the temperature difference between the hot and cold reservoirs. The greater the difference the greater the efficiency. The efficiency of a real engine is further limited by the amount of heat lost through friction and conduction convection and radiation.

b. Diesel burns at a higher temperature, thus diesel engines operate with a greater temperature difference and hence a higher efficiency.

c. In principle, by increasing the hot reservoir temperature you would increase engine efficiency, so you would want a hotter burning fuel, and a hotter engine. However this would be more dangerous with chance of fire. At higher temperatures there would be more expansion of pistons, cylinders etc. If there is differential expansion because of the use of different materials then the engine would not function as well.

B. Activity Questions:

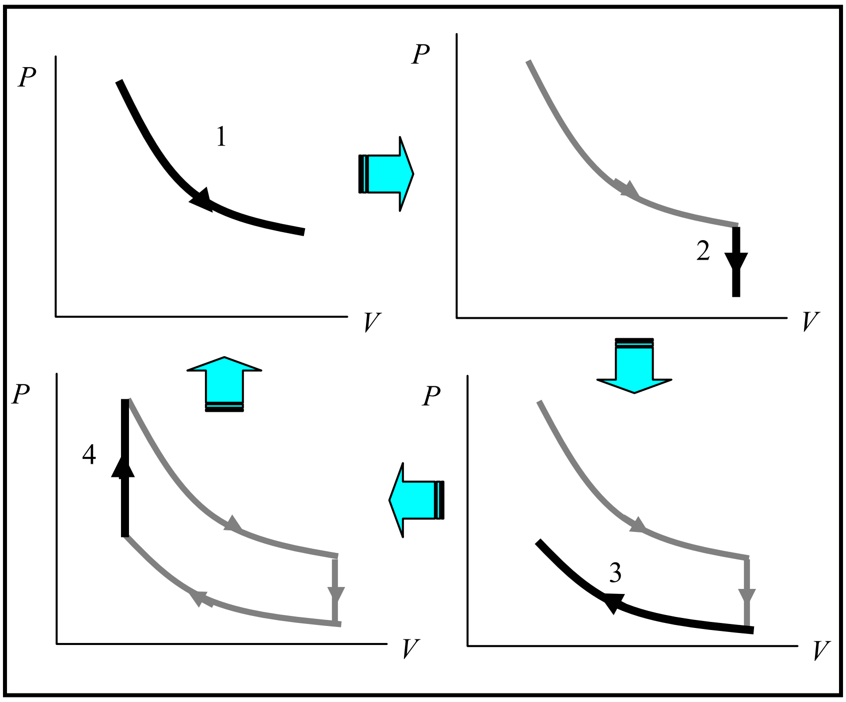
1. Stirling engine

1. Isothermal expansion at T_H. Left piston moves down and heat Q_H is transferred to the gas from the left cylinder wall, which is kept hot by the heat reservoir at T_H.

2. Constant volume process – temperature decreases from T_H to T_C as hot gas passes through the wire mesh. The gas heats the mesh. The volumes change by equal amounts.

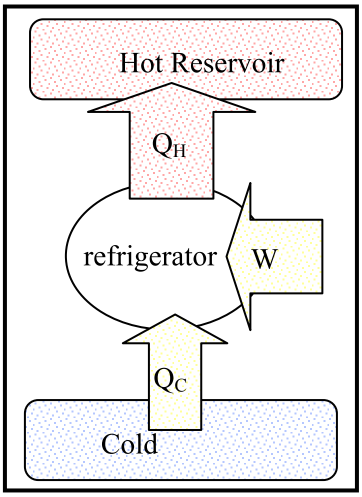
3. Isothermal compression at T_C back to original volume. Heat Q_C is lost from the gas on the right hand side to the cold reservoir.

4. Constant volume process – temperature increases from T_C to T_H, cold gas is pushed across the hot wire mesh and the changes in volume of the two cylinders are equal.



2. Bar Fridge

The cold reservoir of a fridge is the inside of the fridge. The hot reservoir is the outside air at the back of the fridge. An energy flow diagram is shown opposite.



You could not cool a room by leaving the fridge door open, even if the fridge were 100% efficient, the temperature would be unchanged. The second law of thermodynamics says that it is impossible to transfer heat from a cold reservoir to a hot reservoir with no other effect. The other effect is that work must done, and some of this work is invariably dissipated as heat. The nett effect of leaving the fridge door open is to make the room hotter, although it may be slightly cooler directly in front of the fridge door.

C. Quantitative questions:

1. Adiabatic compression in a diesel engine.

We know that $p_1 = 1.01 \times 10^5$ Pa, T_1 = and 300K and $V_1/V_2 = 15$.

a. The final temperature is

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1} = 300(15)^{1.4-1} = 886 \text{ K} = 613\ ^{o}\text{C}$$

b. The final pressure is

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{\gamma} = 1.01 \times 10^5\ (15)^{1.4} = 44.8 \times 10^5 \text{ Pa} = 44 \text{ atm.}$$

If the process had been isothermal the final pressure would have been lower, 15 atm, but because the temperature also increased the final pressure was higher. The greater pressure attained during the adiabatic compression causes the fuel to ignite spontaneously when it is injected into the cylinders near the end of the compression stroke, without the need for spark plugs.

c. In an adiabatic process we know that $Q = 0$, so therefore $W = -\Delta U$.

For an ideal gas, $\Delta U = nc_v(T_2 - T_1)$ so $W = -\Delta U = nc_v(T_1 - T_2)$.

The number of moles, n, is

$$n = \frac{p_1V_1}{RT_1} = \frac{(1.01\times10^{5}\ \mathbf{Pa})(1.00\times10^{-3}\ \mathbf{m})}{(8.315\ \mathbf{J.mol^{-1}.K^{-1}})(300\ \mathbf{K})} = 0.0405 \text{ mol.}$$

so now we can find W:

$W = nc_v(T_1 - T_2) = 0.0405 \text{ mol} \times 20.8 \text{ J.mol}^{-1}. (300 \text{ K} - 886 \text{ K}) = -494$ J.

Note that the work is negative because the gas is compressed, i.e. work is done on it.

2. Brent is making some ice cubes for a cocktail party. He pours 2 litres of water at 15°C into ice cube trays and puts them in the freezer.

a. The thermal energy to be removed is:

$Q = mc\Delta T + mL = 2\text{kg} \times 4.18 \text{ kJ.kg}^{-1}.\text{K}^{-1} \times 15 \text{ K} + 2\text{kg} \times 333.5 \text{ kJ.kg}^{-1} = 125.4 \text{ kJ} + 667 \text{ kJ} = 792.4$ kJ.

b. The coefficient of performance is n = heat removed/ work done by the system = Q/W.

Work done by freezer is $W = Q/n$ = 792.4 kJ / 4.8 = 165 kJ.

c. If n were larger then for the same amount of heat removed, the work done by the freezer would be less. Therefore the ice cubes would freeze more quickly for the same amount of power supplied. The coefficient of performance is a measure of the efficiency of a refrigerator, the greater n, the more efficient the freezer.