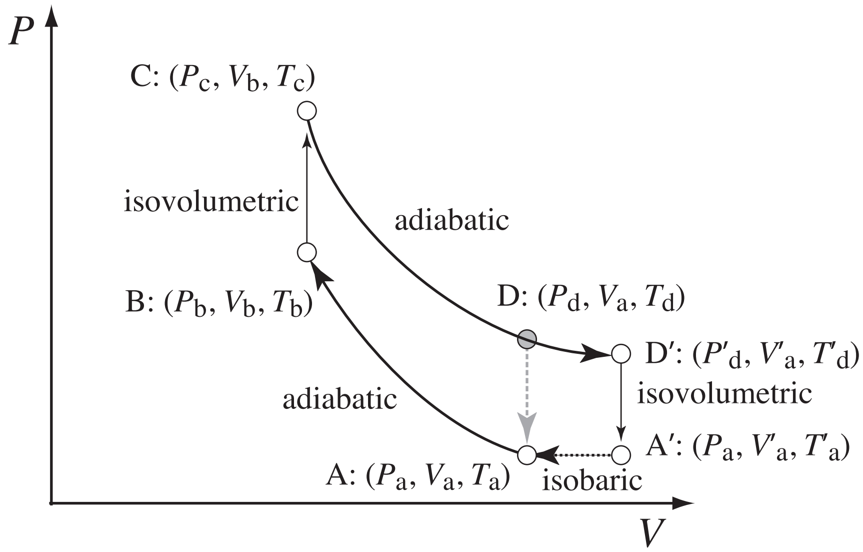
General Physics II: Tutorial Material 13

1) Heat pump is used to warm up a room at temperature T_1 by transferring thermal energy from outside at temperature T_2, where $T_1 > T_2$ i.e. the outside is colder than the room, using work done to the heat pump. Show that a heat pump is more economical than heating the room directly with the work by computing the efficiency of the heat pump using the Carnot cycle.

2) In the Otto cycle, the volume ratio in the expansion, C→D, is identical to that for the compression, A→B, and is given by V_a/V_b. Some hybrid cars use Atkinson cycle where the volume ratios are different. This is realised by changing the timing of exhaust or/and intake and also called Miller cycle. In order to compare its performance with the Otto cycle, we consider the Miller cycle to use the same volume of air-gasoline mixture gas, V_a, for the adiabatic compression and the condition for ignition, i.e. the adiabatic compression of the air-gasoline mixture starts at $A(P_a, V_a, T_a)$.
The Miller cycle shown in the *P*-*V* plot below is the following:
i) At A, the piston is somewhere in the middle of the cylinder. The volume, V_a, is filled with the air-gasoline mixture and all the valves are closed.
ii) The piston moves up to the top (B) and the gas is ignited and explodes (B→C).
iii) The piston is pushed down (C→D') and reaches the lowest position of the cylinder (D').
iv) The piston goes up to exhaust the burnt gas (exhaust valve open) and goes down to take in the air-gasoline mixture (intake valve open), which corresponds to the isovolumetric reduction of the pressure, D'→A', where at A' the cylinder is back at the lowest position.
v) When the piston starts to move up, the intake valve is still open, thus isobaric compression starts till arriving at A where the in-take valve closes.
vi) Back to the original state and ready for the next cycle.
Figure below is the *P*-*V* plot for a Miller cycle, together with an equivalent Otto cycle.



Show that an engine with Miller cycle (A→B→C→D'→A'→A) is more efficient than that with Otto cycle (A→B→C→D→A).

3) Two questions related to thermal conductivity and Fourier's law for the heat flow rate (*)

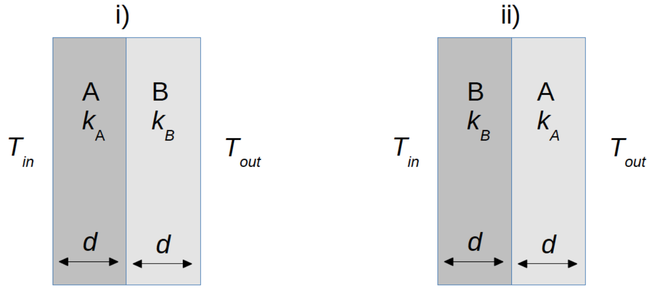
$$\dot{Q} \equiv \frac{dQ}{dt} = -kA\frac{dT}{dx}$$

I) Let us consider a wall consisting of two plates, A and B: both plates have a thickness d with thermal conductivities, k_A and k_B, respectively, and $k_A > k_B$. We use this wall for a house and can make i) surface A facing inside of the house and ii) surface B facing inside of the house. In winter when the outside temperature, T_{out}, is lower than the room temperature T_{in}, i.e. $T_{in} > T_{out}$.

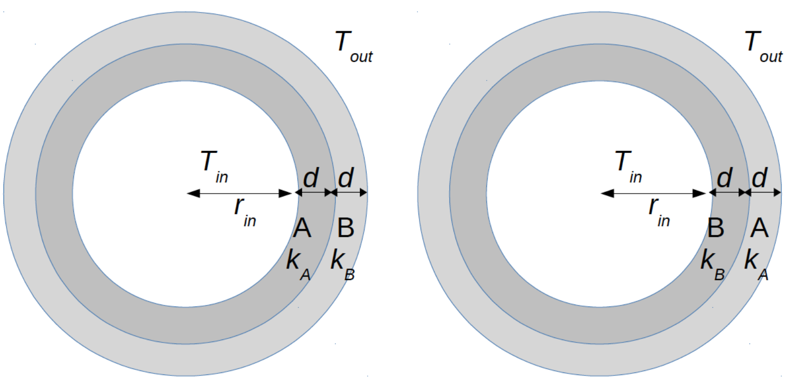
a. Calculate the heat flow rate from the room to outside through wall with configuration i).

b. Calculate the heat flow rate from the room to outside through wall with configuration ii).

c. Are the temperature profiles through the wall from the inside to the outside surface for the two configurations same or different? Which configuration loses more thermal energy to outside?



II) A pipe consists of the two layers of material with a same thickness d. The inner radius of the pipe is r_{in}. Two material A and B with thermal conductivities, k_A and k_B, respectively, are available for the layers where $k_A > k_B$. This pipe is used to transport hot water with a temperature T_{in} through cold outside with a temperature of T_{out}, where $T_{in} > T_{out}$. Figures below show the cross-sections of the pipes.



a. Calculate the heat rate from the water to outside for a pipe where the inner layer with material A.

b. Calculate the heat rate from the water to outside for a pipe where the inner layer with material B.

c. Are the radial temperature profiles different between the two configurations? Which configuration loses more thermal energy to outside?