Question 1 (20 marks)

a) A tank has a volume V_0 at a reference temperature T_o, and is made of a material with linear coefficient of thermal expansion α_m. At temperature T_o, it is completely filled by a liquid with volumetric coefficient of thermal expansion β_l. Derive an expression for the volume ΔV that overflows from the tank at a temperature T.

b) Using the equation of state for an ideal gas, derive an expression for the density ρ of an ideal gas in terms of the pressure P, temperature T, molecular mass m and constants.

c) Derive an expression for the volumetric coefficient of thermal expansion β for an ideal gas at constant pressure P. Give your answer in terms of the temperature T.

d) An ideal gas, initially with pressure P_o, volume V_o and temperature T_o is compressed isothermally to P_1, V_1 and T_o (step A). The gas then expands adiabatically to P_o, V_2 and T_2 (step B). It then returns isobarically to its orginal state P_o, V_o and T_o (step C).

i) Sketch a P,V diagram for this process. On the axes, indicate P_o, P_1, V_o, and V_1. Also label the steps A, B and C and indicate their direction with arrows.

ii) Q is the heat added to the gas, W is the work done by the gas, and ΔU is the change in its internal energy. In the table provided, indicate with the symbols +, – and 0 whether the terms are positive, negative or zero for each step.

Step	Q	W	ΔU
A (isothermal compression)			
B (adiabatic expansion)			
C (isobaric)			
Whole cycle (Σ)			

Question 2 (21 marks)

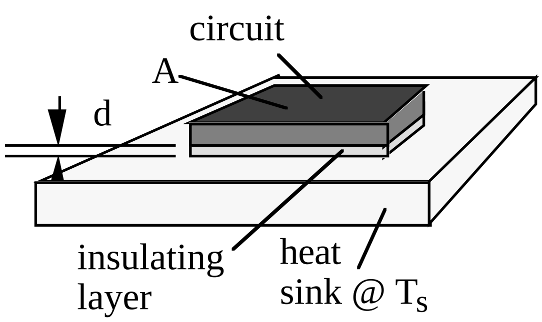
a)

i) What is the rms speed of an oxygen molecule ($^{16}O_2$) at T = 300 K?

ii) What is the rms speed of a hydrogen molecule ($^{1}H_2$) at T = 300 K?

iii) The escape velocity for the Earth is 11 km.s^{-1}. Comment briefly on your answer to the previous questions and the current composition of the Earth's atmosphere. (Your comments could be a few complete sentences, ***or*** it could be in point form.)

b)



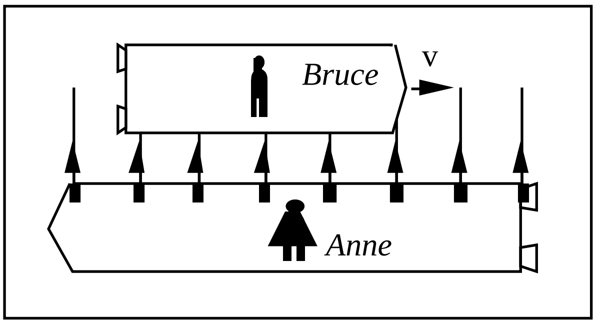
A thin integrated circuit is mounted on a circuit board, from which it is separated by good thermal (as well as electrical) insulator. Its package is black and has an area on the board of A = 10 cm^2. All of the electrical energy used by the device is lost as heat. It is to be used in vacuum, so there is no convection. The device is mounted above a heat sink, which is maintained at T_s = 30° C. The (electrically insulating) packaging under the circuit forms a layer of thickness d = 0.6 mm, which has a thermal conductivity k = 1.2 mW.K^{-1}m^{-1}. The surroundings are all black and are at temperature T_s = 30° C.

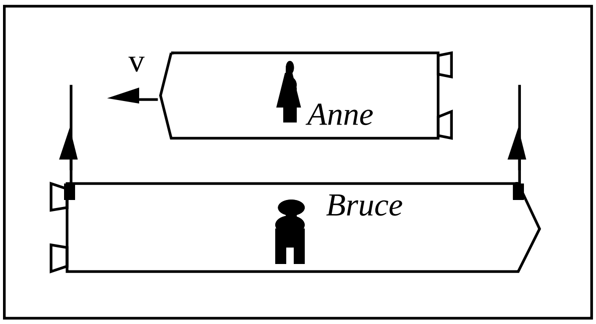
i) What power does the circuit dissipate by conduction to the heat sink when it is at an operating temperature of 50 °C?

ii) What power does the circuit dissipate by radiation exchange to the surroundings when it is at an operating temperature of 50 °C? You may neglect heat radiation through the vertical faces of the package and through the insulating layer.

iii) *Briefly* describe a simple way in which you could increase the power dissipation, and *briefly* explain why it would work. (Two sentences should suffice.)

Question 3 (13 marks)





Anne and Bruce are travelling in antiparallel directions in spaceships. Their relative speed is 0.66 c, where c is the speed of light. Their spaceships are in most respects similar. However, Anne thinks that her ship is longer than Bruce's. Bruce thinks that his ship is longer than Anne's.

i) The proper length of both ships is L_o = 7.5 m. How long does Anne measure Bruce's ship to be?

They see that the two ships will pass close by, and they decide to settle their agreement. Anne installs a set of powerful pulsed lasers along her ship, which she places one metre apart. As the ships pass, she simultaneously fires one pulse from each laser, as shown in the figure at left. She asks Bruce to count the number of marks left by the laser blasts on his ship.

ii) How many laser marks will Bruce measure?

iii) How could Bruce explain the result of Anne's experiment? (Your explanation could be several sentences, ***or*** it could be in point form.)

iv) Explain why Bruce's explanation is possible. (Your explanation could be several sentences, ***or*** it could be in point form.)

Bruce conducts a different demonstration, as shown in the figure at right. He simultaneously fires two beams from the ends of his ship and at right angles to the direction of travel. These beams travel at approximately c. "Look," he radios to Anne, "one of my beams went ahead of your ship, the other one went behind it. That must prove that your ship is shorter".

v) How can Anne explain the result of Bruce's experiment?

Question 4 (10 marks)

An electron is accelerated through a potential difference of 20 MV.

i) What is its kinetic energy?

ii) What is its momentum?

iii) If the electron collides with a massive, stationary target (such as a heavy atom), what is the mimimum wavelength of a photon that may be produced by such a collision?

iv) If the electron collides with a positron that has been accelerated through 20 MV, what is the mimimum wavelength of a photon that may be produced by such a collision?

Question 5 (16 marks)

i) Sketch the principal elements of an experiment involving light that demonstrates an effect associated with ***waves***. Name the effect, and explain very briefly what happens and why this demonstrates wave-like properties. (Your explanation could be several sentences, ***or*** it could be in point form. In either case, a diagram may be useful.)

ii) Sketch, or give a brief description of an experiment involving light that demonstrates an effect associated with ***particles***. Name the effect, and explain very briefly what happens and why this demonstrates properties normally associated with particles. (Your explanation could be several sentences, ***or*** it could be in point form. In either case, a diagram may be useful.)

iii) de Broglie proposed that electrons could have a wavelength. Explain briefly the phenomenon that he explained using this wavelength. (Your explanation could be several sentences, ***or*** it could be in point form. In either case, a diagram may be useful.)