PHYS1221 end of year test 2004

The following equations may be used without proof.

$PV = NkT = nRT$ $\quad P = \frac{1}{3}\rho\overline{v^2}$ $\quad I = e\sigma T^4$

$x' = \gamma(x - vt)$ $\quad t' = \gamma(t - vx/c^2)$ $\quad u'_x = \dfrac{u_x - v}{1 - u_x v/c^2}$ $\quad \gamma = \dfrac{1}{\sqrt{1 - v^2/c^2}}$ $\quad E^2 = p^2c^2 + m^2c^4$

$\lambda_{max}T = 2898\ \mu m.K$ $\quad \lambda - \lambda' = \dfrac{h}{m_e c}(1 - \cos\theta)$ $\quad E_n = -\dfrac{13.6\ eV}{n^2}$ $\quad p = h/\lambda$

$m_e = 9.1\ 10^{-31}$ kg $\quad m_p = 1.67\ 10^{-27}$ kg $\quad e = 1.6\ 10^{-19}$ C $\quad h = 6.63\ 10^{-34}$ Js

$k = 1.38\ 10^{-23}\ JK^{-1}$ $\quad \sigma = 5.67\ 10^{-8}\ Wm^{-2}K^{-4}$ $\quad \mathbf{F}_e = \dfrac{1}{4\pi\varepsilon_o}\dfrac{q_1q_2}{r^2}\hat{\mathbf{r}}$ $\quad \mathbf{F}_g = G\dfrac{Mm}{r^2}\hat{\mathbf{r}}$

Question 1 (14 marks)

i) In one sentence, give a formal definition of temperature.

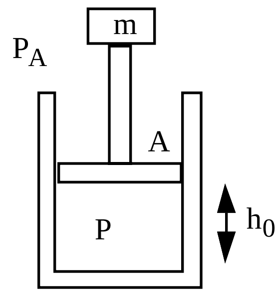
ii) Define heat capacity. If your definition is an equation, define the terms in it.

iii) Define specific heat (≡ specific heat capacity). If your definition is an equation, define the terms in it.

iv) **(1221 only)** How much would the sea level rise if the temperature of the ocean increased by 2°C? For this problem, neglect the effects of melting ice. Assume that the ocean has an average depth of 4 km. Also assume that its area does not increase as sea-level rises. (Expressed as a proportion, this assumption is in fact very good.)

The volumetric coefficient of thermal expansion of water is $2.1\ 10^{-4}\ °C^{-1}$.

v) Pneumatic or air suspension has some advantages (and some disadvantages) in comparison with springs. In this question we consider an idealised version of air suspension. A volume V_0 of air at atmospheric pressure P_A and temperature T_0 is sealed in a piston of area A that slides without leaks or friction in a cylinder. The air may be considered as an ideal gas with molar mass 0.029 kg.kmol^{-1}. The piston is then loaded with a mass m, that includes the mass of the piston. The system is allowed to reach mechanical and thermal equilibrium at T_0.



Showing your working, derive an expression for h_0, the equilibrium height of the piston in the cylinder as shown in the sketch in terms of the parameters given above and the gas constant.

Question 2 (29 marks)

i) An athlete runs up a mountain. His altitude increases at a steady rate of 0.55 m.s^{-1}. His climbing is 20% efficient: that is, for each Joule of biochemical energy he converts, 20% is converted into increased gravitational potential energy. The athlete has a mass of 80 kg and a total skin area of 1.8 m^2. His skin temperature T_a is uniform and 34°C. His surroundings have a temperature T_s that is uniform and 30°C. Assume that both the skin and the surroundings have emissivities of 0.8. As in the original Olympics, the athlete is nude. (If you are under 18 years of age, the athlete is wearing a small costume, whose effects we shall neglect.)

a) Showing your working, calculate the rate at which he is converting biochemical energy into heat.

b) Showing your working, calculate the ***nett*** rate of heat loss by radiation.

c) If all the heat produced by his body were lost by sweating, so that his body temperature stays constant, and if all of his sweat evaporates, calculate the rate of water loss. Convert your answer into litres per hour. Assume that the latent heat of evaporation of water at skin temperature is 2.5 MJ.kg^{-1}.

d) Suppose that (perhaps because of dehydration), his sweating slowed that the total rate of heat loss by the athlete fell to 500 W. Assume that he continues producing heat at the rate you calculated in (a). Calculate how long it would take for his body temperature to rise by an average of 2°C. (The specific heat of the body is 4 kJ.kg^{-1}.°C^{-1}.)

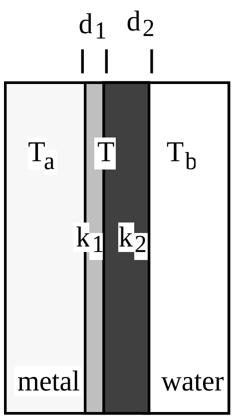
ii) An ideal gas, initially with pressure P_o, volume V_o and temperature T_o is compressed isothermally to P_1, V_1 and T_o (step A). The gas then expands adiabatically to P_o, V_2 and T_2 (step B). It then returns isobarically to its original state P_o, V_o and T_o (step C).

a) 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.

b) 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)			

iii)



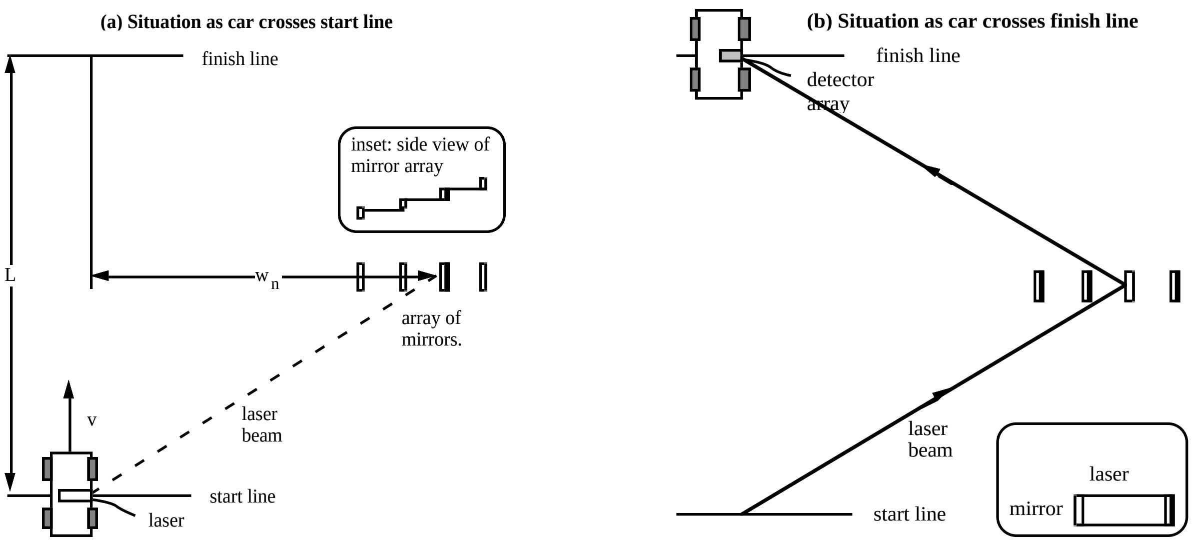
A large, metal object is maintained at constant, uniform temperature T_a. It is coated with two uniform, thin layers of insulating material. The first coat has thickness d_1 and thermal conductivity k_1. The second coat has thickness d_2 and thermal conductivity k_2. The coated metal object is immersed in water at constant, uniform temperature T_b. A section of the object and coatings is shown in the sketch.

By considering the flow of heat through the coating, determine the temperature T at the interface between the two coatings, in steady state.

Question 3 (14 marks)

Jane has entered her car for a new event: the Bathurst Time Trial. Her car (a '61 Holden fitted with fins and stripes to increase speed) is believed to be so fast that a special timing system has been devised. It works like this: at the start, a laser in the car sends a beam laterally towards an array of mirrors set up at the half-way point of the course, as shown in the two diagrams below (not to scale). The course has length L and the mirrors are at different distances w_n from the track. (The mirrors are also at slightly different heights and the beam is spread in the vertical direction so that it can hit all of them, but this detail is unimportant for the following question.)

At the finish line, a reflected beam is received by one of a set of detectors fixed to the side o the car. From the height of the detector that received it, one can tell which mirror reflected the beam. The further the reflector is far from the track, then the further light has travelled during the time trial, so the slower the car. The aim in this race is to have a low value of w_n.



i) The judges of the race determine that the pulse received by the car at the finish line was reflected by the nth mirror, at a distance w_n from the track. From this observation, the judges then calculate their value of the time t_{judge} taken by Jane for the event. Derive an expression for t_{judge} in terms of L, w_n and c, the speed of light.

ii) Using your result from (i), give an expression for the speed v that the judges will record for the event. Express your answer in terms of c and the ratio w_n/L.

iii) Rearrange your answer to (ii) to express L/w_n in terms of c and v.

iii) Jane also observes that the light has been reflected from the nth reflector. From this observation alone, and *without* using the Lorentz transformation equations, give an expression for the time t_{Jane} that Jane will calculate as the time she took to complete the distance L. Your expression should not involve v.

Explain in one or two sentences how you derived your answer.

iv) Jane and the judge determine different times: $t_{judge} \neq t_{Jane}$. Nevertheless, from independent measurements such as the Doppler shift in light, they both agree on the speed v.

Describe how Jane (who understands relativity as well as motor mechanics) would explain the difference between the two results for t_{judge} and t_{Jane}.

v) Describe how the judges (who also understand relativity) would explain the difference between the two results for t_{judge} and t_{Jane}.

Question 4 (8 marks)

i) Is the mass of the nucleus of an iron atom greater or less than the sum of the masses of the protons and neutrons that make it up? Briefly explain the origin of the difference Δm, and give an expression for this quantity.

ii) The mean lifetime of muons travelling at negligible speed in a laboratory on Earth is 2.20 μs. The mean lifetime of high-speed muons in a cosmic ray shower is measured by an Earth observer to be 16.0 μs. Calculate the speed of the cosmic ray muons.

Question 5 (13 marks)

i) Give an example of a commercially available device that works on the principle of quantum mechanical tunnelling by electrons. With the aid of a brief sketch, explain how it works.

ii) a) What are virtual particles? (Your explanation should refer to an expression from the Special Theory of Relativity and to Heisenberg's Uncertainty Principle. Four or five clear sentences.)

b) The range of the electromagnetic interaction is at least very large, and possibly infinite. The range of the strong nuclear force is finite. In a few clear sentences, explain the cause of this difference. (Hint: you may refer to your answer to part a.)