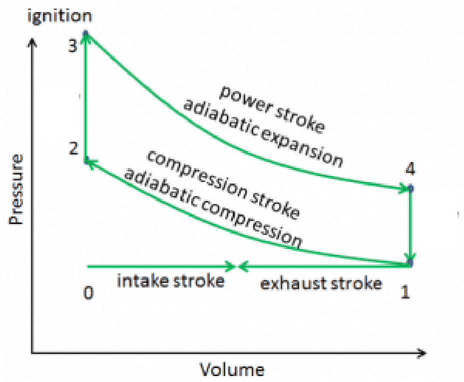
Trent University: PHYS 2700H – Thermal Physics 2024 – 2025

Midterm: Monday Feb 10, 2025 **Name:**___________________

Allowed: Formula sheet (given), calculator, 1 hour 50 minutes

PART 1 – answer questions **1-8** in your exam booklet and **then** use your scratch card:
One scratch = **100%**; two scratches = **33%**; three scratches = **25%** (part 1 total is 50%)
PART 2 – answer questions **9 & 10** in the exam booklet provided (each question here is worth 25%)

Qu's 1-2) The internal combustion engine can be modelled to reasonable accuracy by an Otto cycle, with the cycle labelled 1234 as shown. Let W be the net work done **by** the gas over the entire cycle, and Q_{ij} be the heat **in** between any step i and its consecutive step j.



1) With these sign conventions, which of the following statements about this cycle is most correct?

A. $Q_{12} = Q_{34} = 0 \;\; ; \;\; Q_{23} < 0$

B. $Q_{12} = Q_{34} > 0 \;\; ; \;\; Q_{23} > 0$

C. $Q_{12} = Q_{34} = 0 \;\; ; \;\; Q_{23} > 0$

D. $Q_{12} < 0 \;\; ; \;\; Q_{34} > 0 \; ; \; Q_{23} > 0$

E. $Q_{12} < 0 \;\; ; \;\; Q_{34} > 0 \; ; \; Q_{23} = Q_{41} = 0$

2) Which of the following expressions most correctly represents the *efficiency* of this engine?

A. $\frac{W}{Q_{23}}$ **B.** $\frac{W}{Q_{23} - Q_{41}}$ **C.** $\frac{W}{Q_{12}}$ **D.** $\frac{W}{Q_{23} + Q_{41}}$ **E.** $\frac{W}{Q_{21}}$

3) Suppose a Carnot engine operates between two reservoirs with a temperature difference of $100\ ^\circ\mathrm{C}$ and uses a working substance that changes volume between a minimum of V_1 and a maximum of V_2, doing net work W each cycle. Which of the following adaptations would give the greatest absolute increase in efficiency, assuming it still operates as a Carnot engine?

A. The hot and cold reservoirs are unchanged, but the change in *volume* of the working substance is doubled, from $2V_1$ to $2V_2$.

B. The hot and cold reservoirs are unchanged, but the *quantity* of working substance is increased so the net work each cycle is $2W$.

C. The temperature of the hot reservoir is increased by $10\ ^\circ\mathrm{C}$.

D. The temperature of the hot reservoir is decreased by $10\ ^\circ\mathrm{C}$.

E. The temperature of the cold reservoir is deceased by $10\ ^\circ\mathrm{C}$.

Qu's 4-5) The resistance to heat lost through walls and windows etc. is described in North America using imperial units by the "R" value, and using SI units by the "RSI" value. These are defined, with units given in brackets, as follows:

$$P \equiv \frac{1}{\mathrm{R}} A\Delta T \quad \left\{\begin{matrix} P \text{ in BTU/hr} \\ A \text{ in ft}^2 \\ \Delta T \text{ in °F} \end{matrix}\right\} \qquad\qquad P \equiv \frac{1}{\mathrm{RSI}} A\Delta T \quad \left\{\begin{matrix} P \text{ in W} \\ A \text{ in m}^2 \\ \Delta T \text{ in °C} \end{matrix}\right\}$$

where P is the rate of heat flow through the barrier, A is the area of the barrier, and ΔT is the temperature difference across the barrier. Additional relationships between imperial and SI units are:

$$T(\text{in °F}) = \tfrac{9}{5}T(\text{in °C}) + 32 \qquad ; \qquad L(\text{in ft}) = 3.28 \times L(\text{in m})$$

4) What are the RSI values for a wall with $\mathrm{R} = 22\ \text{hr.ft}^2\text{.°F/BTU}$, and a window with $\mathrm{R} = 4\ \text{hr.ft}^2\text{.°F/BTU}$?

A. $\mathrm{RSI}_{\text{wall}} = 10.3\ \text{m}^2\,\text{°C/W}$
$\mathrm{RSI}_{\text{window}} = 1.87\ \text{m}^2\,\text{°C/W}$

B. $\mathrm{RSI}_{\text{wall}} = 1.03\ \text{m}^2\,\text{°C/W}$
$\mathrm{RSI}_{\text{window}} = 0.187\ \text{m}^2\,\text{°C/W}$

C. $\mathrm{RSI}_{\text{wall}} = 37.4\ \text{m}^2\,\text{°C/W}$
$\mathrm{RSI}_{\text{window}} = 6.80\ \text{m}^2\,\text{°C/W}$

D. $\mathrm{RSI}_{\text{wall}} = 3.88\ \text{m}^2\,\text{°C/W}$
$\mathrm{RSI}_{\text{window}} = 0.705\ \text{m}^2\,\text{°C/W}$

E. $\mathrm{RSI}_{\text{wall}} = 3.74\ \text{m}^2\,\text{°C/W}$
$\mathrm{RSI}_{\text{window}} = 0.680\ \text{m}^2\,\text{°C/W}$

5) Suppose we model a home as a rectangular cuboid of length 40 ft, width 25 ft, and height 16 ft. As per building code, 20% of the total area of the vertical faces contains windows. Suppose that the temperature inside is $20\ \text{°C}$ and outside is $-20\ \text{°C}$. Using the equations above, what is the rate of heat flow of the remaining vertical wall area and of the windows (we neglect doors and other structural details)?

A. $P_{\text{walls}} = 16\ \text{kW}$
$P_{\text{windows}} = 22\ \text{kW}$

B. $P_{\text{walls}} = 8.4\ \text{kW}$
$P_{\text{windows}} = 12\ \text{kW}$

C. $P_{\text{walls}} = 4.6\ \text{kW}$
$P_{\text{windows}} = 2.2\ \text{kW}$

D. $P_{\text{walls}} = 2.6\ \text{kW}$
$P_{\text{windows}} = 4.2\ \text{kW}$

E. $P_{\text{walls}} = 1.6\ \text{kW}$
$P_{\text{windows}} = 2.2\ \text{kW}$

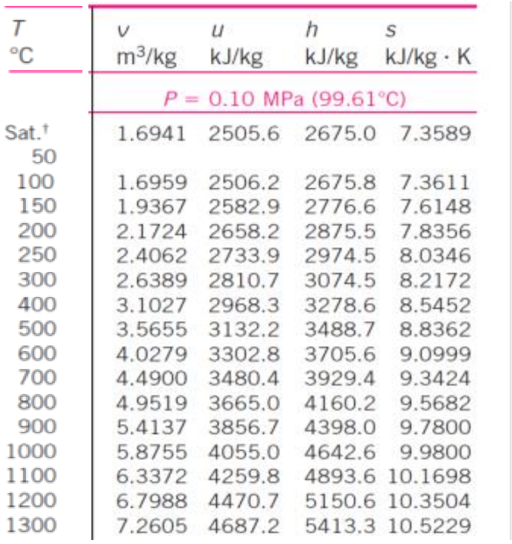
6) Milk at coffee shops is often heated using a continuous flow of hot water vapour. If 15 g of water vapour at 100 °C is used to heat whole milk from 20 °C to 50 °C, what mass of milk can be heated? (Treat the specific heat of water to be 4.184 J/g/°C; the latent heat of vapourization of water to be 2260 kJ/kg; and the specific heat of whole milk to be 3.77 J/g/°C).

A. 110 g **B.** 180 g **C.** 220 g **D.** 330 g **E.** 380 g

7) 2.2 g of nitrogen gas (N_2) is held in a cylinder at atmospheric pressure and at 5 °C. Treating this as an ideal gas, what is it volume? (Recall that one mole of nitrogen molecules has a mass of 28 g).

A. 1.4 m^3 **B.** 2.5 litres **C.** 1.8 litres **D.** 1.8 m^3 **E.** 1.4 litres

8) Based on the steam table on the right, which of the following statements is most correct about some of the heat capacities of water vapour?



T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 0.10 MPa (99.61°C)			
Sat.†	1.6941	2505.6	2675.0	7.3589
50				
100	1.6959	2506.2	2675.8	7.3611
150	1.9367	2582.9	2776.6	7.6148
200	2.1724	2658.2	2875.5	7.8356
250	2.4062	2733.9	2974.5	8.0346
300	2.6389	2810.7	3074.5	8.2172
400	3.1027	2968.3	3278.6	8.5452
500	3.5655	3132.2	3488.7	8.8362
600	4.0279	3302.8	3705.6	9.0999
700	4.4900	3480.4	3929.4	9.3424
800	4.9519	3665.0	4160.2	9.5682
900	5.4137	3856.7	4398.0	9.7800
1000	5.8755	4055.0	4642.6	9.9800
1100	6.3372	4259.8	4893.6	10.1698
1200	6.7988	4470.7	5150.6	10.3504
1300	7.2605	4687.2	5413.3	10.5229

A. c_p increases from about 1.5 J/g/°C at boiling temperature to about 2.0 J/g/°C at about 1000 °C.

B. c_p increases from about 2.0 J/g/°C at boiling temperature to about 2.5 J/g/°C at about 1000 °C.

C. c_v increases from about 2.0 J/g/°C at boiling temperature to about 2.5 J/g/°C at about 1000 °C.

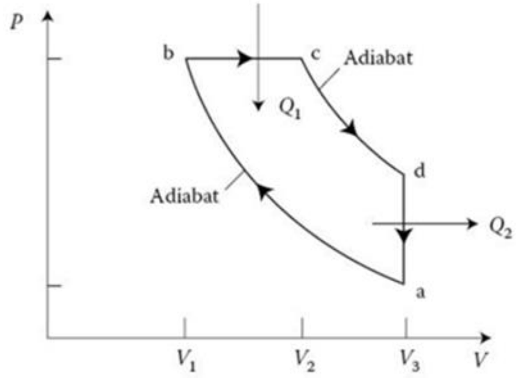
D. c_v increases from about 2.7 J/g/°C at boiling temperature to about 4.6 J/g/°C at about 1000 °C.

E. c_p increases from about 2.5 J/g/°C at boiling temperature to about 3.5 J/g/°C at about 1000 °C.

PART II –answer both questions in the exam booklet provided

9. a) An *ideal gas* operates as the working substance in a *Carnot engine*. Select such a process and draw this on the following diagrams, providing for each clear explanatory labels:
i) a *PV* diagram
ii) a *PT* diagram
iii) a *UV* diagram
iv) a *UT* diagram
v) a *UH* diagram

b) A Carnot engine with an arbitrary working substance is operated between two heat reservoirs of $400\ \mathrm{K}$ and $300\ \mathrm{K}$.
i) If the engine receives 1200 kJ from the hot reservoir per cycle, how much heat does it reject to the cold reservoir?
ii) How much work is done in one cycle, and what is the efficiency of this Carnot engine?



10. A model of a Diesel engine cycle is shown on the right. We shall assume air is the working substance, and that it acts as an ideal gas. Suppose that the *expansion ratio,* $r_e = V_3 / V_2$, is 5, and the *compression ratio,* $r_c = V_3 / V_1$, is 16. Suppose the engine has four cylinders and the *total engine displacement* (= max volume – min volume for all cylinders) is 2.4 L.

a) Find V_1, V_2 and V_3.

b) If $P_a = 1\ \mathrm{atm}$ find the (V, P) coordinates of a, b, c and d.

c) The work done **on** a gas when changed adiabatically from a state (P_i, V_i) to (P_f, V_f) is given by:

$$W = \frac{P_i V_i}{\gamma - 1}\left[\left(\frac{V_i}{V_f}\right)^{\gamma-1} - 1\right]$$

Find the net work done by the total engine in one cycle.