

AFTER I GIVE THE SIGNAL TO BEGIN YOU CAN REMOVE THIS SHEET. DO NOT TURN IT IN!

162sp26t1b – Once the exam has officially started, remove the top sheet. The remaining sheets comprise your exam. It is each student's individual responsibility to ensure the instructor has received her or his completed exam. Any exams not received by the instructor earn zero points. Smart watches, phones, or other devices (except scientific calculators) are not permitted during the exam.

$1 \text{ kg} \cdot \frac{\text{m}}{\text{s}^2} = 1 \text{ N}$	$1 \text{ N} \cdot \text{m} = 1 \text{ J}$	$1 \text{ Pa} = 1 \frac{\text{N}}{\text{m}^2}$	$1 \text{ W} = 1 \frac{\text{J}}{\text{s}}$
$N_A = 6.022 \times 10^{23}$	$P_0 = 1.013 \times 10^5 \text{ Pa}$	$\sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \cdot \text{K}^4}$	$1 \text{ Cal} = 1 \text{ kcal} = 4.184 \text{ kJ}$
$R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$	$1 \text{ m}^3 = 1000 \text{ L}$	$1 \text{ L} \cdot \text{kPa} = 1 \text{ J}$	$k_B = \frac{R}{N_A} = 1.381 \times 10^{-23} \frac{\text{J}}{\text{K}}$
$\Delta x = \frac{1}{2} a_x t^2 + v_{ix} t$	$v_x = \frac{dx}{dt}$	$a_x = \frac{dv_x}{dt}$	$\omega = 2\pi f = \frac{2\pi}{T}$
$\Sigma \vec{F} = m\vec{a}$	$\Sigma \vec{\tau} = I\vec{\alpha}$	$\mathcal{P} = \frac{dE}{dt}$	$\mathcal{P} \approx \frac{Q}{\Delta t}$
$\Delta L = L_0 \alpha \Delta T$	$\Delta A = A_0 (2\alpha) \Delta T$	$c = \frac{1}{m} \cdot \frac{dQ}{dT}$	$Q = mc\Delta T$
$\mathcal{P} = kA \frac{dT}{dx} \approx \frac{kA\Delta T}{L}$	$R = \frac{L}{k}$	$\mathcal{P}_{\text{delivered}} \approx \frac{A\Delta T}{\sum_{i=0}^N R_i}$	$Q = \pm mL$
$\mathcal{P}_{\text{radiated}} = \sigma A \epsilon T^4$	$\mathcal{P}_{\text{NET emitted}} = \sigma A \epsilon (T^4 - T_{\text{env}}^4)$	$PV = nRT = Nk_B T$	$\bar{K} = \frac{1}{2} m \overline{v^2} = \frac{3}{2} Nk_B T$
$n = \frac{N}{N_A}$	$n = \frac{m}{M}$	$Q = nC_V \Delta T$	$Q = nC_P \Delta T$
$C_V = \frac{f}{2} R$	$C_P = C_V + R = \frac{f+2}{2} R$	$\gamma = \frac{C_P}{C_V} = \frac{f+2}{f}$	$\Delta E_{\text{int}} = \frac{f}{2} Nk_B \Delta T = \frac{f}{2} nR\Delta T$
$v_{\text{RMS}} = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3RT}{M}}$	$C = \frac{1}{n} \cdot \frac{dE_{\text{int}}}{dT}$	$W_{\text{by gas}} = \int_i^f P dV$	$f_{\text{diatomic}} = \begin{cases} 3 & T < 80 \text{ K} \\ 5 & 200 \text{ K} < T < 1000 \text{ K} \\ 7 & T > 2000 \text{ K} \end{cases}$
$\Delta E_{\text{int}} = Q_{\text{in}} - W_{\text{by}}$	$n_V(E) = n_0 \exp\left(-\frac{E}{k_B T}\right)$	$\frac{N}{V} = \int_{E_i}^{E_f} n_0 \exp\left(-\frac{E}{k_B T}\right) dE$	$f(v) dv = \left(\frac{m}{2\pi k_B T}\right)^{3/2} \exp\left(-\frac{mv^2}{2k_B T}\right) 4\pi v^2 dv$
$W_{\text{on gas by piston}} = -W_{\text{by gas on piston}}$	$P_i V_i^\gamma = P_f V_f^\gamma$	$I_0 = \int_0^\infty e^{-ax^2} dx = \frac{1}{2} \sqrt{\frac{\pi}{a}}$	$I_1 = \int_0^\infty x e^{-ax^2} dx = \frac{1}{2a}$
$W_{\text{by gas isotherm}} = nRT \ln \frac{V_f}{V_i}$	$W_{\text{by gas adiabat}} = \frac{1}{1-\gamma} (P_f V_f - P_i V_i)$	$I_2 = \int_0^\infty x^2 e^{-ax^2} dx = \frac{1}{4} \sqrt{\frac{\pi}{a^3}}$	$I_3 = \int_0^\infty x^3 e^{-ax^2} dx = \frac{1}{2a^2}$
$\Delta E_{\text{int}} = nC_V \Delta T = \frac{f}{2} Nk_B \Delta T = \frac{f}{2} nR\Delta T = \frac{f}{2} (P_f V_f - P_i V_i)$		$I_4 = \int_0^\infty x^4 e^{-ax^2} dx = \frac{3}{8} \sqrt{\frac{\pi}{a^5}}$	$I_5 = \int_0^\infty x^5 e^{-ax^2} dx = \frac{1}{a^3}$
$\eta = \frac{W_{\text{Net}}}{Q_{\text{in}}} = 1 - \frac{ Q_c }{ Q_h }$	$\eta_{\text{Carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}$	$I_{2n} = (-1)^n \frac{d^n I_0}{da^n}$	$I_{2n+1} = (-1)^n \frac{d^n I_1}{da^n}$
$COP_{\text{heat}} = \frac{ Q_{\text{to hot}} }{W_{\text{on gas}}}$	$COP_{\text{cool}} = \frac{ Q_{\text{from cold}} }{W_{\text{on gas}}}$	$S = k_B \ln W$	$dS = \frac{dQ}{T}$
			$T_K = T_C + 273.15$

$T = 10^{12}$	$G = 10^9$	$M = 10^6$	$k = 10^3$	$c = 10^{-2}$	$m = 10^{-3}$	$\mu = 10^{-6}$	$n = 10^{-9}$	$p = 10^{-12}$	$f = 10^{-15}$	$a = 10^{-18}$
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Assumes standard atmospheric pressure $P_0 = 1.013 \times 10^5 \text{ Pa} = 1 \text{ atm}$		
Substance	Specific heat $\left(\frac{\text{J}}{\text{kg} \cdot \text{K}}\right)$	Molar specific heat $\left(\frac{\text{J}}{\text{mol} \cdot \text{K}}\right)$
Aluminum	900	24.3
Brass	380	
Copper	386	24.5
Ethyl alcohol	2400	111
Glass	840	
Gold	126	25.6
Granite	790	
Ice (at $-10 \text{ }^\circ\text{C}$)	2200	36.9
Lead	128	26.4
Mercury	140	28.3
Silver	235	24.9
Steam (at $110 \text{ }^\circ\text{C}$)	2100	35.2
Tungsten	134	24.8
Water	4186	75.2
Zinc	387	25.2

Assumes standard atmospheric pressure $P_0 = 1.013 \times 10^5 \text{ Pa} = 1 \text{ atm}$				
Substance	Melting		Boiling	
	$T_{\text{melting}} \text{ (}^\circ\text{C)}$	$L_f \left(\frac{\text{kJ}}{\text{kg}}\right)$	$T_{\text{boiling}} \text{ (}^\circ\text{C)}$	$L_v \left(\frac{\text{kJ}}{\text{kg}}\right)$
Aluminum	660	380	2450	2720
Copper	1083	134	2595	5069
Ethyl alcohol	-114	104	78.3	854
Gold	1063	64.5	2660	1578
Hydrogen	-259.3	58.6	-252.9	452
Lead	327	24.5	1750	871
Mercury	-38.9	11.8	357	272
Nitrogen	-210	25.5	-195.8	199
Oxygen	-218.8	13.8	-183.0	213
Silver	961	88.3	2193	2336
Water	0.00	334	100.0	2256

Substance	$\alpha \left(\frac{10^{-6}}{^\circ\text{C}}\right)$ valid for $T \approx 20 \text{ }^\circ\text{C}$
Aluminum	24
Brass	19
Concrete	12
Copper	17
Diamond	1.2
Fused quartz	0.59
Glass (ordinary)	9
Glass (Pyrex)	4
Gold	14
Iron	12
Lead	29
Silver	18
Steel	11
Ice (at $0 \text{ }^\circ\text{C}$)	51

Thermal Conductivities	
Substance	$k \left(\frac{\text{W}}{\text{m} \cdot \text{K}}\right)$
Aluminum	220
Brass	110
Red Brick	0.6
Concrete	0.8
Copper	400
Fiberglass	0.048
Ice @ $0 \text{ }^\circ\text{C}$	2
Lead	35
Silver	420
Glass	1.0
Steel	50
Dry Air @ $20 \text{ }^\circ\text{C}$ Used in multi-pane windows	0.026

Emissivity in Infrared	
Substance	ϵ
Aluminum (anodized)	0.77
Aluminum (polished)	0.05
Brass (highly polished)	0.03
Brass (oxidized)	0.61
Copper (polished)	0.05
Copper (oxidized)	0.65
Red Brick	0.90
Glass	0.90
Ice	0.97
Paper (white)	0.68
Paper (white bond)	0.93
Paper (black)	0.90
Cardboard	0.81

Name: _____

A scientist has two identical Styrofoam cups. Cup A contains ethyl alcohol at 20.0 °C. Cup B contains an unknown amount of water (also at 20.0 °C). The scientist has two identical metal masses (same material), each heated to 100.0 °C. The mass of each piece of metal is equal to the mass of the ethyl alcohol in Cup A. She drops the piece of metal into each cup and observes the cups experience identical temperature changes. Assume the liquid & metal in each cup are perfectly insulated from the environment. Assume the metal is one of the metals on our chart (but you don't know which one).

1a) Which best describes the mass of water in Cup B? Circle the best answer.

<i>More than</i> the mass of the ethyl alcohol	<i>Equal to</i> the mass of the ethyl alcohol	<i>Less than</i> the mass of the ethyl alcohol	Impossible to determine without more info
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1b) Which best describes the equilibrium temperature reached by ethyl alcohol in Cup A? Circle the best answer.

> 60°C	≈ 60°C	< 60°C	Impossible to determine without more info
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Two red bricks (same shape, material, and mass) are placed on wire racks and allowed to cool in a room at temperature 0.00 °C. At some instant, brick A is at 4.00 °C while brick B is at 2.00°C.

2a) According to a physicist, which best describes the temperatures of the bricks? Circle the best answer.

Brick A has <i>twice</i> the temperature of Brick B	The two bricks have <i>approximately</i> equal temperature (within 1%)	The two bricks have <i>exactly</i> equal temperature	None of the other answers is accurate
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2b) Which brick requires more time to cool 1.00 °C?

Brick A	Brick B	Same time	Impossible to determine without more info
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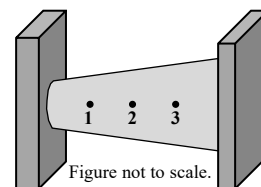
2c) Which brick experiences a positive entropy change during the first 1.00 °C of cooling?

Brick A	Brick B	Both bricks	Neither brick	Impossible to determine without more info
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2d) Strictly speaking, which brick experiences a larger entropy change during the first 1.00 °C of cooling?

Brick A	Brick B	Same entropy change	Impossible to determine without more info
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A tapered rod is used to conduct heat from left to right. The system is in steady state. Several equally spaced points are labeled at various positions on the rod to simplify communication.



3a) Which reservoir is warmer? Circle the best answer.

Left	Right	Same Temp	Impossible to determine without more info
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3b) Assume Q_{12} is heat flow during 1 second between points 1 & 2. Similarly, Q_{23} is heat flow during 1 second between points 2 & 3. Which of the following statements is true? Circle the best answer.

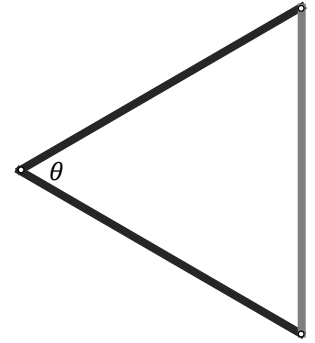
$Q_{12} > Q_{23}$	$Q_{12} = Q_{23}$	$Q_{12} < Q_{23}$	Impossible to determine without more info
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3c) Consider the temperature differences ΔT_{12} between points 1 & 2 and ΔT_{23} between points 2 & 3.

Which temperature difference is larger? Circle the best answer.

$\Delta T_{12} > \Delta T_{23}$	$\Delta T_{12} = \Delta T_{23}$	$\Delta T_{12} < \Delta T_{23}$	Impossible to determine without more info
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At room temperature of 20.0 °C, an equilateral triangle is built by connecting an aluminum rod (right, grey rod) to two rods of another material (black rods). Each rod has length s . The connection points are pins designed to allow the angles of the triangle to flex. Assume thermal expansion is negligible in the *black* rods (compared to the aluminum rod). Please notice there is a question at the bottom of the page...



4a) Which best describes how height & width of the triangle are affected as its temperature increases? Circle the best answer. Again, assume the black rods experience negligible length change.

Height & width both decrease	Height increases & width decreases	Impossible to determine without more info
Height & width both increase	Height decreases & width increases	

***4b) Determine an expression for angle θ as a function of temperature T . Assume temperature *increases*. Please do *not* plug in a numerical value for α .

4b	
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4c) In the real world, the black rods will also expand (very slightly) with temperatures. Which best describes how this fact affects your result for θ as a function of temperature?

Our function <u>overestimates</u> the amount the angle changes	Our function for the angle is exactly correct	Our function <u>underestimates</u> the amount the angle changes	Impossible to determine without more info
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A 875-gram piece of silver at $99.9\text{ }^{\circ}\text{C}$ is dropped onto a block of ice (initially at $-3.00\text{ }^{\circ}\text{C}$) in an insulated container. The two materials are allowed to reach thermal equilibrium. During this process, 4.00% of the ice melts. Assume negligible heat transfers to container or the environment as the materials reach thermal equilibrium.

*****5) Determine the mass of ice.

5	
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A diatomic ideal gas in a piston is taken from state A to state B using the thermodynamic process indicated in the plot.

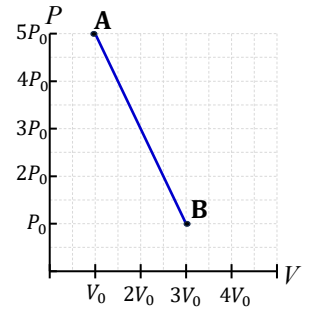
6a) Which best describes the work done ON the gas during this process?

Positive	Zero	Negative	Impossible to determine without more info
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6b) Which best describes the change in thermal energy during this process?

Positive	Zero	Negative	Impossible to determine without more info
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6c) This was not part of the original test. Skip it and do it after you finish the timed test for extra practice. Which best describes heat added to the gas: positive, negative, zero, or impossible to determine?



A scientist observes a distant star emitting 3.43×10^{24} W of power into space. By analyzing the spectrum of light emitted, she determines the star's surface temperature is 8888 K. Assume the star is a perfect blackbody and the average temperature of space surrounding the star is negligible.

***7) Determine the star's diameter. **Answer in scientific notation.**

7	
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The speeds of molecules in a 2D-dimensional gas can be modeled by the distribution function

$$f(v) = 2\pi v \left(\frac{m}{2\pi k_B T} \right) \exp\left(-\frac{mv^2}{2k_B T} \right)$$

****8) Determine the average of v^3 for a gas subject to *this* distribution.

If you show work for the 3D distribution, you get ZERO points.

- Show your work or you will receive zero credit.
- Write your result in terms of $m, k_B,$ & T with all terms in a single fraction under the radical.
- Your work should be easy to follow or you may lose points.
- Simplify your final result or you will not receive full credit.
- Put your final, simplified result in the box.

8	
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A PV -diagram for an engine using a *monatomic* gas is shown. The cycle runs clockwise. Temperature at point **3** is 1046 K. Assume work is done by the gas during every cycle (as in a 2-stroke engine). Note: $P_1 = 1461.5$ kPa. The other volumes & pressures line up on gridlines. To make things line up, one of the temperatures is unrealistically high!

9a) Determine the number of moles of gas to 3 sig figs.

9b) Determine T_1 & T_2 with 4 sig figs.

9c) Determine the best value to use for the adiabatic constant γ based off discussions in class & homework.

***9d) Fill in the chart below.

Assume the points are 0.25 star per box with a free 0.25 star.

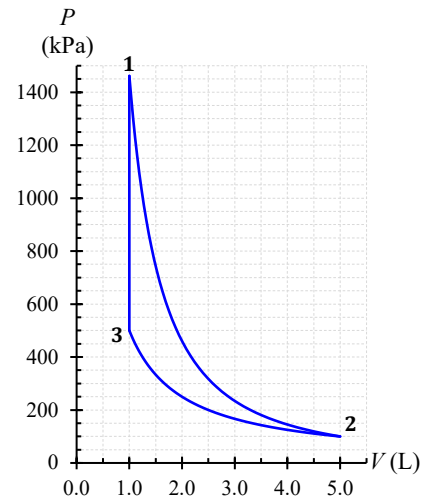
No partial credit. Incorrect \pm sign gets zero points.

I recommend keeping an extra sig fig and using an underline to indicate the rounding digit for all numbers in the chart.

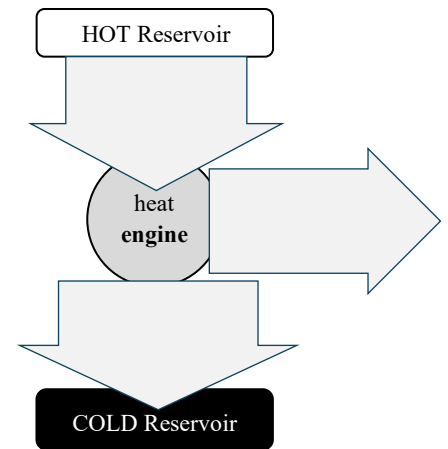
**9e) Fill in the arrows on the engine diagram below AND compute efficiency of this engine.

You are expected to know what #'s & units to write in each arrow.

9a	$n =$
9b	$T_1 =$ $T_2 =$
9c	$\gamma =$



	Process Name	Q_{in} (J)	$W_{by\ gas}$ (J)	ΔE_{int} (J)
1 \rightarrow 2				
2 \rightarrow 3				
3 \rightarrow 1				
	For the Entire Cycle			



Efficiency =

I originally wanted to put this problem on the test but had to cut something because the test was too long. After you finish the timed portion of the test, you should do this problem as extra practice.

Watch out! Extra credit is often time-consuming for a small number of points. Focus on regular credit and attempt this question only if you finish the rest of the test early.

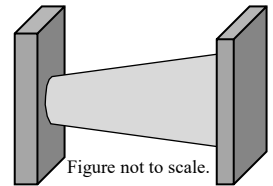
***Extra Credit: Reconsider the tapered rod. Assume the reservoirs are separated by distance L .

Assume the left plate has horizontal position $x = 0$. The rod's radius is given by the function

$$r(x) = r_0 + \alpha x$$

where r_0 & α are positive constants and x is horizontal position. In steady state the tapered rod conducts heat at rate \mathcal{P} when the temperature difference between reservoirs is ΔT .

Determine rod conductivity. Simplify your result.



EC	
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