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

162sp25t2a – 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.

$1\ \text{kg}\cdot\frac{\text{m}}{\text{s}^2} = 1\ \text{N}$	$1\ \text{N}\cdot\text{m} = 1\ \text{J}$	$1\ \text{Pa} = 1\frac{\text{N}}{\text{m}^2}$	$1\ \text{W} = 1\ \frac{\text{J}}{\text{s}}$
$N_A = 6.022\times10^{23}$	$P_0 = 1.013\times10^{5}\ \text{Pa}$	$\sigma = 5.67\times10^{-8}\frac{\text{W}}{\text{m}^2\cdot\text{K}^4}$	$1\ \text{Cal} = 1\ \text{kcal} = 4.184\ \text{kJ}$
$R = 8.314\frac{\text{J}}{\text{mol}\cdot\text{K}}$	$1\ \text{m}^3 = 1000\ \text{L}$	$1\ \text{L}\cdot\text{kPa} = 1\ \text{J}$	$k_B = \frac{R}{N_A} = 1.381\times10^{-23}\frac{\text{J}}{\text{K}}$
$\Delta x = \frac{1}{2}a_x t^2 + v_{ix}t$	$v_x = \frac{dx}{dt}$	$a_x = \frac{dv_x}{dt}$	$\omega = 2\pi f = \frac{2\pi}{\mathbb{T}}$
$\Sigma\vec{F} = m\vec{a}$	$\Sigma\vec{\tau} = I\vec{\alpha}$	$\mathcal{P} = \frac{dE}{dt}$	$\mathcal{P} \approx \frac{Q}{\Delta t}$
$\Delta L = L_0\alpha\Delta T$	$\Delta A = A_0(2\alpha)\Delta T$	$c = \frac{1}{m}\cdot\frac{dQ}{dT}$	$Q = mc\Delta T$
$\mathcal{P} = kA\frac{dT}{dx} \approx \frac{kA\Delta T}{L}$	$R = \frac{L}{k}$	$\mathcal{P}_{delivered} \approx \frac{A\Delta T}{\sum_{i=0}^{N} R_i}$	$Q = \pm mL$
$\mathcal{P}_{radiated} = \sigma A\epsilon T^4$	$\mathcal{P}_{\substack{NET \\ emitted}} = \sigma A\epsilon(T^4 - T_{env}^4)$	$PV = nRT = Nk_BT$	$\overline{K} = \frac{1}{2}m\overline{v^2} = \frac{3}{2}Nk_BT$
$n = \frac{N}{N_A}$	$n = \frac{m}{\mathcal{M}}$	$Q = \boldsymbol{n}C_V\Delta T$	$Q = \boldsymbol{n}C_P\Delta T$
$C_V = \frac{f}{2}R$	$C_P = C_V + R = \frac{f+2}{2}R$	$\gamma = \frac{C_P}{C_V} = \frac{f+2}{f}$	$\Delta E_{int} = \frac{f}{2}Nk_B\Delta T = \frac{f}{2}nR\Delta T$
$v_{RMS} = \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3RT}{\mathcal{M}}}$	$C = \frac{1}{n}\cdot\frac{dE_{int}}{dT}$	$W_{\boldsymbol{by}\ gas} = \int_i^f P\,dV$	$f_{diatomic} = \begin{cases} 3 & T < 80\ \text{K} \\ 5 & 200\ \text{K} < T < 1000\ \text{K} \\ 7 & T > 2000\ \text{K} \end{cases}$
$\Delta E_{int} = Q_{in} - W_{\boldsymbol{by}}$	$n_V(E) = n_0\exp\left(-\frac{E}{k_BT}\right)$	$\frac{N}{V} = \int_{E_i}^{E_f} n_0\,exp\left(-\frac{E}{k_BT}\right)dE$	$f(v)\,dv = \left(\frac{m}{2\boldsymbol{\pi}k_BT}\right)^{3/2}\exp\left(-\frac{mv^2}{2k_BT}\right)4\pi v^2\,dv$
$W_{\substack{\boldsymbol{on}\ gas \\ \boldsymbol{by\ piston}}} = -W_{\substack{\boldsymbol{by}\ gas \\ \boldsymbol{on\ piston}}}$	$P_iV_i^\gamma = P_fV_f^\gamma$	$I_0 = \int_0^\infty e^{-ax^2}dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}$	$I_1 = \int_0^\infty xe^{-ax^2}dx = \frac{1}{2a}$
$W_{\substack{\boldsymbol{by}\ gas \\ isotherm}} = nRT\ln\frac{V_f}{V_i}$	$W_{by\ gas\ adiabat} = \frac{1}{1-\gamma}(P_fV_f - P_iV_i)$	$I_2 = \int_0^\infty x^2e^{-ax^2}dx = \frac{1}{4}\sqrt{\frac{\pi}{a^3}}$	$I_3 = \int_0^\infty x^3e^{-ax^2}dx = \frac{1}{2a^2}$
$\Delta E_{int} = nC_V\Delta T = \frac{f}{2}Nk_B\Delta T = \frac{f}{2}nR\Delta T = \frac{f}{2}(P_fV_f - P_iV_i)$		$I_4 = \int_0^\infty x^4e^{-ax^2}dx = \frac{3}{8}\sqrt{\frac{\pi}{a^5}}$	$I_5 = \int_0^\infty x^5e^{-ax^2}dx = \frac{1}{a^3}$
$\eta = \frac{W_{Net}}{Q_{in}} = 1 - \frac{\lvert Q_c\rvert}{\lvert Q_h\rvert}$	$\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$	$I_{2n} = (-1)^n\frac{d^nI_0}{da^n}$	$I_{2n+1} = (-1)^n\frac{d^nI_1}{da^n}$
$COP_{heat} = \frac{\lvert Q_{to\ hot}\rvert}{W_{\boldsymbol{on}\ gas}}$	$COP_{cool} = \frac{\lvert Q_{from\ cold}\rvert}{W_{\boldsymbol{on}\ gas}}$	$S = k_B\ln W$	$dS = \frac{dQ}{T}$
			$T_K = T_C + 273.15$

$\text{T} = 10^{12}$	$\text{G} = 10^{9}$	$\text{M} = 10^{6}$	$\text{k} = 10^{3}$	$\text{c} = 10^{-2}$	$\text{m} = 10^{-3}$	$\mu = 10^{-6}$	$\text{n} = 10^{-9}$	$\text{p} = 10^{-12}$	$\text{f} = 10^{-15}$	$\text{a} = 10^{-18}$

Assumes standard atmospheric pressure $P_0 = 1.013 \times 10^5$ Pa = 1 atm		
Substance	**Specific heat** $\left(\frac{J}{kg \cdot K}\right)$	***Molar* specific heat** $\left(\frac{J}{mol \cdot K}\right)$
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 ℃)	2200	36.9
Lead	128	26.4
Mercury	140	28.3
Silver	235	24.9
Steam (at 110 ℃)	2100	35.2
Tungsten	134	24.8
Water	4186	75.2
Zinc	387	25.2

	Assumes standard atmospheric pressure $P_0 = 1.013 \times 10^5$ Pa = 1 atm			
	Melting		Boiling	
Substance	$T_{melting}$ (℃)	$L_f \left(\frac{kJ}{kg}\right)$	$T_{boiling}$ (℃)	$L_v \left(\frac{kJ}{kg}\right)$
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	$\alpha \left(\frac{10^{-6}}{℃}\right)$ **valid for** $T \approx 20$ ℃
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 ℃)	51

Thermal Conductivities	
Substance	$k \left(\frac{W}{m \cdot K}\right)$
Aluminum	220
Brass	110
Red Brick	0.6
Concrete	0.8
Copper	400
Fiberglass	0.048
Ice @ 0 ℃	2
Lead	35
Silver	420
Glass	1.0
Steel	50
Dry Air @ 20 ℃ 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 solid cylindrical rod of unknown material has diameter 4.44 mm & length 77.7 cm at room temperature 20.0 °C. The density of the materials is $5.55 \frac{\text{g}}{\text{cm}^3}$. When the rod absorbs 6.66 kJ of heat, its temperature rises to 99.9 °C and its length increases 0.888 mm.

**1a) Determine the mass of the material.

**1b) Determine the specific heat of the material. Answer in standard units.

**1c) Determine the linear expansion coefficient of the rod. Answer in standard units.

1a	
1b	
1c	

Two reservoirs are connected using metal rods as shown at right.
The left reservoir is maintained at 66.6 °C while the right is maintained at -22.2 °C.
The metal rods are cylindrical with equal diameters.
The left metal rod has length 20.0 cm and is made of copper.
The right metal rod has length 10.0 cm and is made of steel.
The system is allowed to reach steady state.
In steady state, 555 J of heat is transferred in 15.00 min.

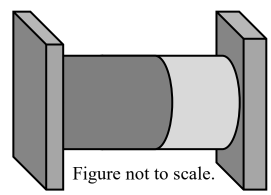


Figure not to scale.

2a) Which direction does heat flow through the metal rods? Circle the best answer.

To the right	To the left	No heat flow	Impossible to determine without more info

***2b) Determine the temperature of the junction (the interface between the two metal rods).

**2c) Determine the diameter of the cylindrical rods.

2b	
2c	

A 7.50 cm diameter brass sphere with mass 1.875 kg is heated in a kiln to 92<u>0</u> ℃. This temperature is below the melting point for this particular type of brass. During the heating process, the brass surface oxidizes. The sphere is removed from the kiln and placed on a stand to cool in a room at temperature 20.0 ℃.

**3a) Estimate the power radiated (net) by the sphere as it begins cooling.

***3b) Estimate temperature change of the sphere during the first 0.333 s of cooling. Assume energy transfers at a constant rate since the temperature change is small during the first 0.333 s.

3a	
3b	

*****4) Derive the average value of v^3 for the Maxwell-Boltzmann speed distribution.
Show your work or you will receive zero credit.

Write your final 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 a box around your final result or you may lose points.

A gas undergoes isothermal expansion.

5a) Does internal energy of the gas increase, decrease, or remain constant during this process? Circle the best answer.

Increase	Decrease	Remain constant	Impossible to determine without more info

5b) Is work done *by the gas* positive, negative, or zero during this process?

Positive	Negative	Zero	Impossible to determine without more info

5c) Is heat added to the gas positive, negative, or zero during this process?

Positive	Negative	Zero	Impossible to determine without more info

5d) Is the entropy change of the gas positive, negative, or zero during this process?

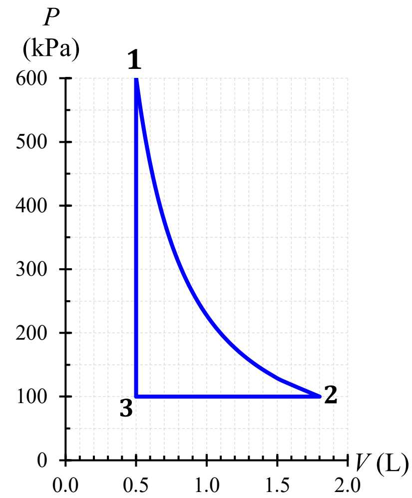
Positive	Negative	Zero	Impossible to determine without more info

***6) An ideal monatomic gas is subject to an unusual process governed by the equation

$$P = \alpha V^2$$

where P is pressure in Pa, α is a constant, and V is measured in m^3.
Derive an expression for work done by the gas changing from some initial state at P_i & V_i to some final state with P_f & V_f. **Your work should be easy to follow or you may lose points. Simplify your final result or you will not receive full credit. The constant α should not appear in your final result. Put a box around your final result.**

A PV-diagram for an engine using diatomic gas is shown at right. The cycle starts at point **1** and runs clockwise. **Note: $P_1 = 601$ kPa…*not* 600.** Temperature at point **2** is 650.2 K. Temperatures range from *about* 180 K to *about* 1100 K. Assume work is done by the gas during every cycle (as in a 2-stroke engine).



7a) Determine the number of moles of gas.
If keeping an extra sig fig (recommended), use an underline to indicate the rounding digit for all numbers on this page.

7b) Determine T_1 & T_3.

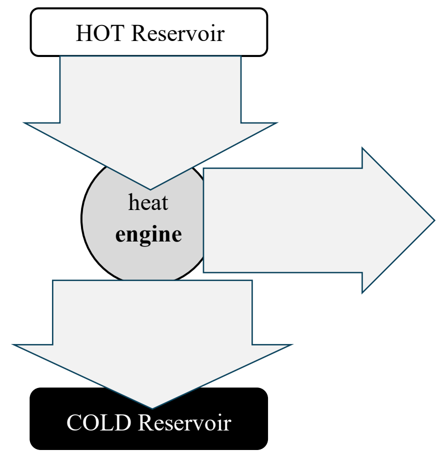
7c) Determine the best value to use for degrees of freedom based off discussions in class & homework.

7a	$n =$
7b	$T_1 =$ $T_3 =$
7c	$f =$

****7d) 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.

**7e) 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.

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



Efficiency =

Extra Credit 1: In question 3 I could have asked for net power radiated or power emitted. Explain why this distinction is unimportant for this question. Support your claim by showing the percent difference between power radiated and NET power radiated. Furthermore, discuss the relative sizes of correction due to heat loss via other heat transfer mechanisms.

Extra Credit 2: Assume you can hold the metal sphere in your hand for a few seconds (without getting burned) when it cools to $50.0\ ℃$. Estimate the time required for the sphere in problem 3 to radiatively cool to $50.0\ ℃$. Work must be easy to follow for credit.

Extra Credit 3: Derive theoretical efficiency (algebraic result) for the heat engine shown in problem 7.
Write your answer in terms of the compression ratio (r_c), adiabatic constant, max temperature (T_{hot}), and min temperature (T_{cold}). Work must be easy to follow for credit.