Question 1: Short Answers (10 pts)

(1a) Indicate if each of the following is a property, and if so, whether it is extensive or intensive.

	Not a Property	Is a Property	
		Extensive	Intensive
Mass		✓	
Temperature			✓
Pressure			✓
Work by a paddlewheel in a process	✓		
Internal Energy		✓	
Internal Energy per unit mass			✓
Specific Volume			✓
Heat Content per unit mass	✓		

(1b) Consider a closed system. Is the value of $\int_1^2 p\,dv$ the same for all processes between state 1 and 2 (here p=pressure, v=specific volume)?

[Yes / [✓ No]].   Depends on path!

(1c) Consider a closed system. Is the value of $\int_1^2 dv$ the same for all processes between state 1 and 2?

[[✓ Yes] / No].   Always, any process, even if highly non-equil.

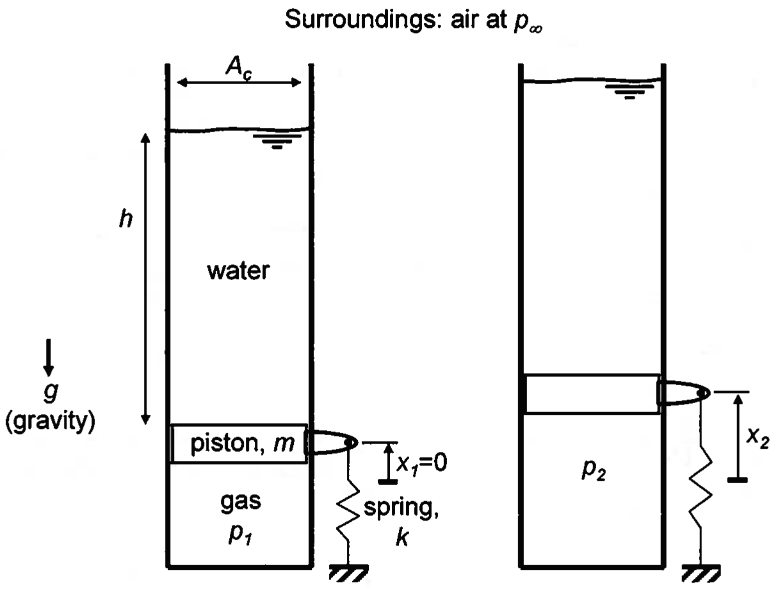
Key point: v is a property.

Problem 2 (20 pts)

A gas (initial pressure p_1) is confined in a cylinder by a heavy piston (of mass m). On top of the piston is a column of water (density ρ, depth h, constant), whose upper surface is exposed to atmospheric air at p_∞.

A bracket joins the piston to a linear spring. The spring is initially relaxed ($x_1 = 0$).

The gas is slowly heated, increasing its pressure (final: p_2) and causing it to gradually expand.



Also Known:

Cylinder cross-sectional area: A_c

Spring constant: k

Initial spring displacement: x_1=0.

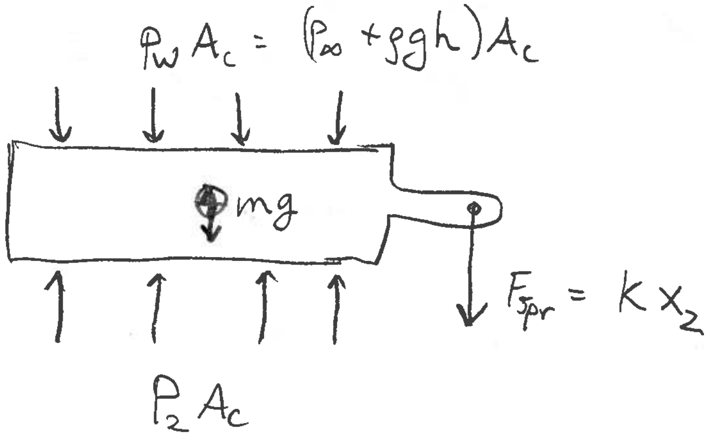
Final spring displacement: x_2 >0.

(a) Draw a free body diagram of the piston in the final state.

(b) Obtain an expression for the final pressure, p_2, in terms of the various given quantities.

(c) Sketch this process on a p-V diagram for the gas.

ⓐ



(...more space for Problem 2)

ⓑ $\sum F_z = 0$ $\qquad P_2 A_c = mg + kx_2 + (P_\infty + \rho g h) A_c$

$$\boxed{P_2 = P_\infty + \rho g h + \frac{mg}{A_c} + \frac{k x_2}{A_c}}$$

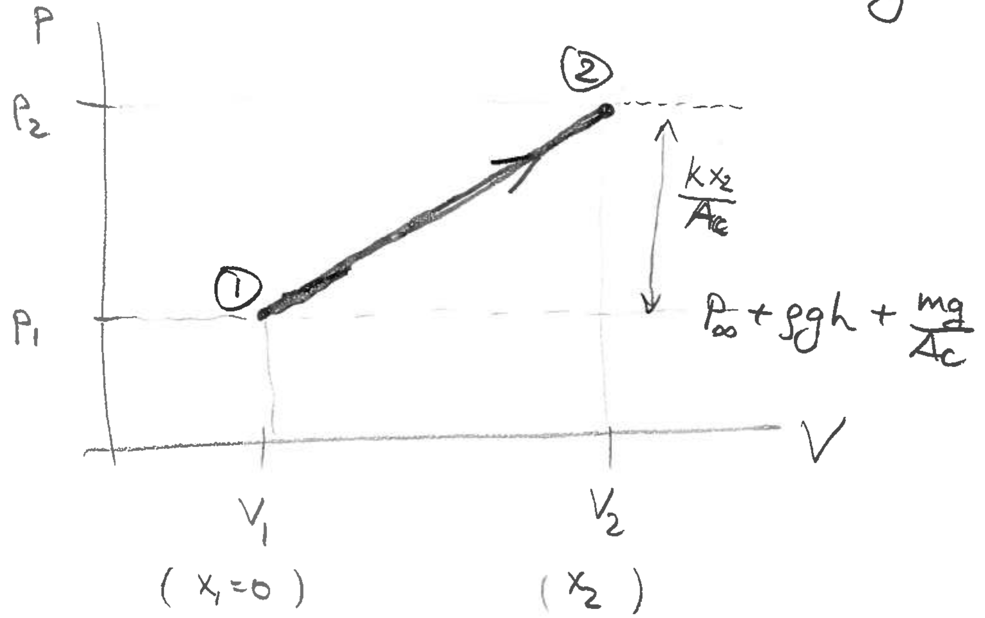
ⓒ $p(V) \Longleftrightarrow p(x)$, where $x = \dfrac{V - V_1}{A_c}$

From (b), $p(x) = a + b \cdot x$,

so $p(V) = c + d \cdot V$

Solid Line (quasi-equil)

Straight Line (for this particular system + process)



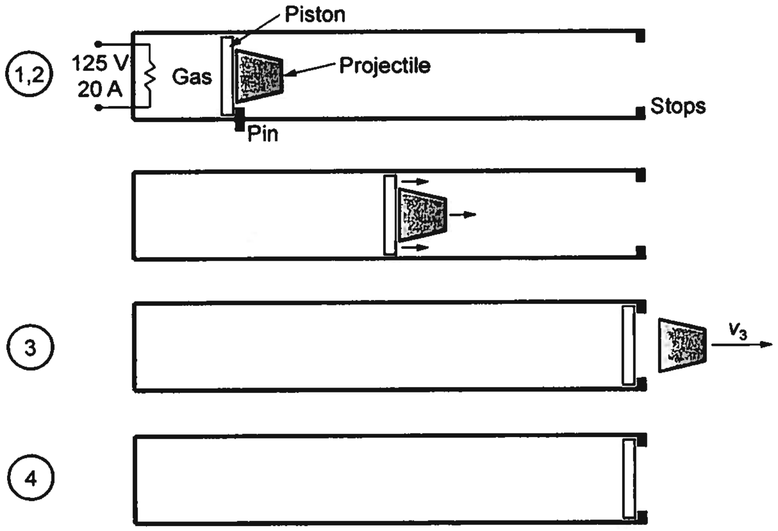
Problem 3 (20 pts) *(This problem contains extra information beyond what is needed for the solution.)*

A gas gun is used to accelerate a heavy metal projectile for an impact manufacturing process.

The gas is initially at T_1, p_1, and the piston is held in a fixed location by a pin.

Then an electrical heater is turned on, drawing a current of **I=20 A** at a voltage of **V=125 V**, for a duration **Δt=40 s**. At this stage the gas conditions are T_2, p_2.

Then the heater is disconnected and the pin removed. The gas rapidly expands, accelerating the piston (of negligible mass) and projectile (***m*=10 kg**) to a velocity v_3, at which point the piston hits the stops and the projectile exits the gun.



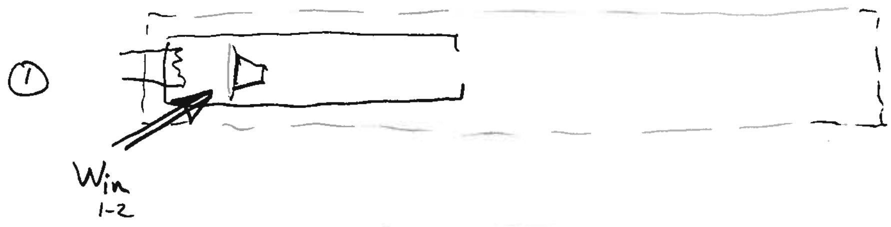
Many hours later, the gas conditions are T_4, p_4. During this long waiting time, there was a gradual heat loss of **Q_{out}=10 kJ** through the walls of the cylinder.

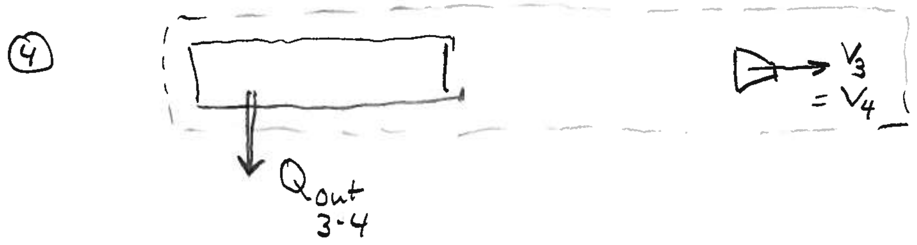
Known Gas Conditions:

	T [K]	p [kPa]	U [kJ]
1	300	100	30
2	(?)	500	(?)
3	(?)	(?)	(?)
4	600	200	90

Find the projectile velocity v_3, in m/s.
(Neglect all friction effects.)

Easiest way: Very large control volume, closed.





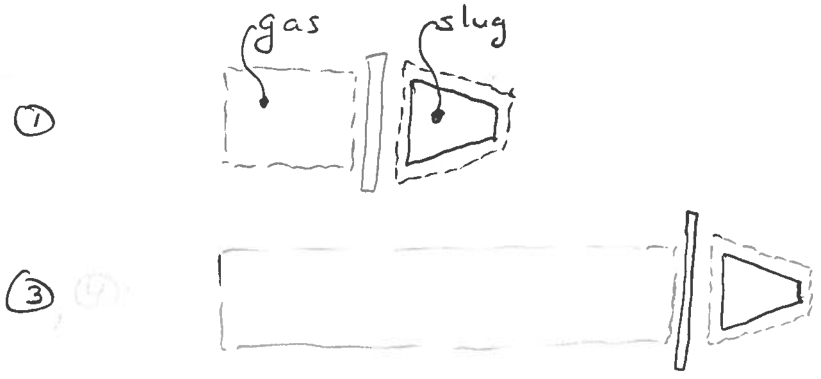
$$E_4 - E_1 = + \underset{14}{Q_{in}} + \underset{14}{W_{in}} + \cancel{\underset{14}{E_{in,mass}}} \to 0$$

$$(U_4 - U_1) + KE_4 - \cancel{KE_1} + (\cancel{PE_4 - PE_1}) = -10\,kJ + \overbrace{IV\Delta t}^{+100\,kJ}$$

$$60\,kJ + \frac{1}{2}mV_4^2 = 90\,kJ \Rightarrow \boxed{V_4 = 77.5\,\frac{m}{s}}\boxed{=V_3}$$

(...more space for Problem 3)

Another option : 2 subsystems.



gas:

(no ΔPE, no KE, no Q_{13}, closed)

$$\Rightarrow U_3 - U_1 = +W_{el} - W_{piston}$$

$$W_{piston} = W_{el} + U_1 - U_3$$

and recognize $U_3 = U_4 + 10\,kJ \Rightarrow W_{piston} = 30\,kJ$

slug

(no ΔPE, no ΔU, no Q_{13}, closed)

$$KE_3 - \cancel{KE_1}^{\,0} = +W_{piston,13}$$

$$\frac{1}{2} m V_3^2 = 30\,kJ$$

$$\boxed{V_3 = 77.5 \frac{m}{s}}$$