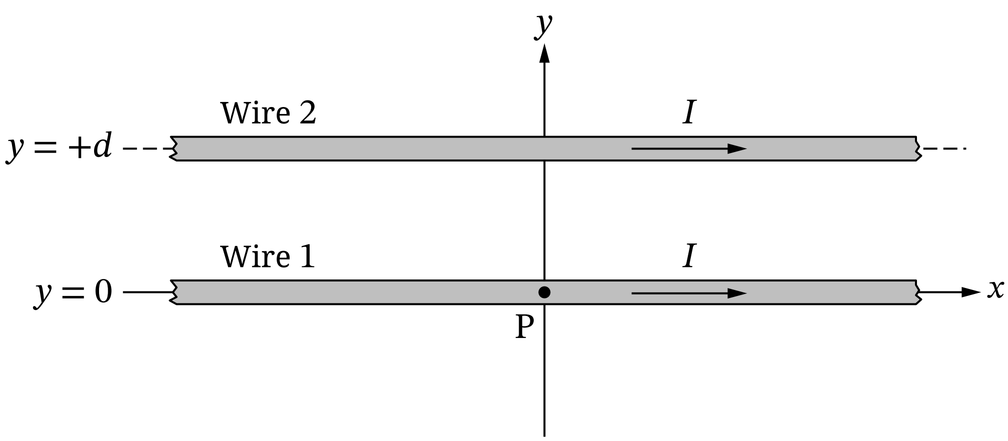
Question 1: Version J

1. Very long Wire 1 carries current I in the $+x$-direction along the line $y = 0$. Very long Wire 2 carries current I in the $+x$-direction along the line $y = +d$. Point P is located along Wire 1 at the origin, as shown in Figure 1. The diameters of the wires are small compared to the distance between the wires. Both wires are in the xy-plane.

Figure 1



Note: Figure not drawn to scale.

A.

i. Complete the following tasks in figures 2 and 3. Use either arrows or the symbols shown in the box above the figures for your response.

- **Indicate** the direction of the magnetic field from Wire 2 at Point P in Figure 2.
- **Indicate** the direction of the magnetic force that is exerted on Wire 1 by Wire 2 in Figure 3.

Symbols	
✕ Into the page	● Out of the page

Magnetic Field from Wire 2 at Point P

Figure 2

Magnetic Force on Wire 1 by Wire 2

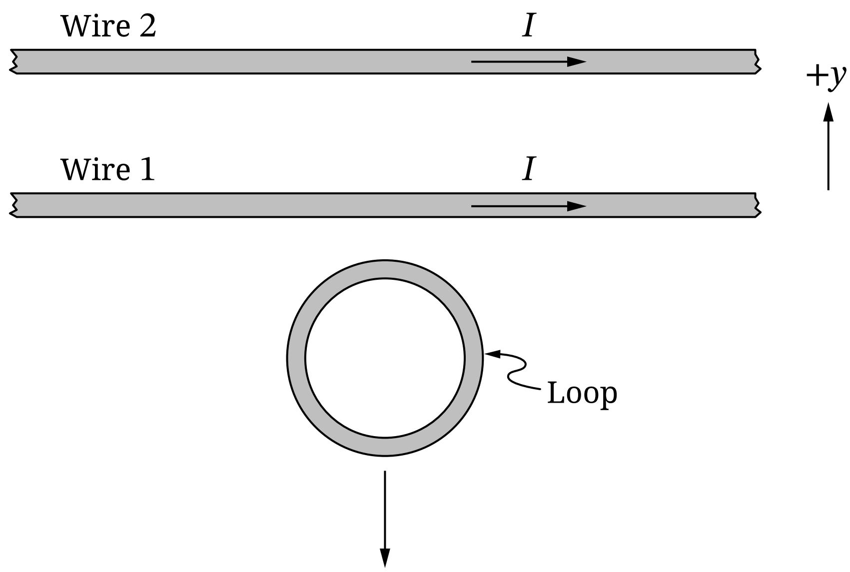
Figure 3

ii. Very long Wire 3 carrying current $2I$ in the $+x$-direction is placed in the xy-plane along the line $y = y_3$. The net magnetic force exerted on Wire 1 by the currents in wires 2 and 3 is zero.

Derive an expression for y_3 in terms of d. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

B. Wire 3 is moved very far away from wires 1 and 2. A circular conducting loop in the *xy*-plane is initially held at rest below Wire 1. The loop is then moved at a constant speed in the $-y$-direction, as shown in Figure 4.

Figure 4



Note: Figure not drawn to scale.

Indicate whether there is a clockwise induced current in the loop, a counterclockwise induced current in the loop, or no induced current in the loop.

______ Clockwise

______ Counterclockwise

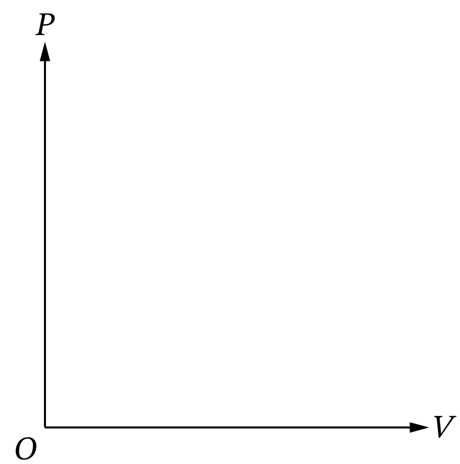
______ There is no induced current in the loop.

Justify your answer.

B. Derive an expression for the internal energy of the gas in terms of M, A, V_0, P_{atm}, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. A block, also of mass M, is placed on the piston at time $t = t_0$ and is slowly lowered. The piston comes to rest at $t = t_f$ when the block is completely released.

On the axes provided, **sketch** the expected relationship between the pressure P and volume V of the gas for the thermodynamic process that the gas undergoes during time interval $t_0 \leq t \leq t_f$. **Draw** an arrow on your sketch to represent the direction of the thermodynamic process.



D. With the block still on the piston, the temperature of the water bath is changed to a new constant temperature T_{new}. The gas occupies the original volume V_0 when the sample of gas and the water bath come to thermal equilibrium.

Indicate whether T_{new} is greater than, less than, or equal to T_0.

______ $T_{new} > T_0$

______ $T_{new} < T_0$

______ $T_{new} = T_0$

Briefly **justify** your answer by referencing at least one feature of your answers to parts A, B, or C.

Question 1: Mathematical Routines (MR) — 10 points

A **(i)** For indicating that the magnetic field is directed into the page in Figure 2 — **Point A1**

For indicating **one** of the following: — **Point A2**

- The magnetic force is directed in the $+y$-direction in Figure 3.
- If the direction is out of the page in Figure 2, the magnetic force is directed in the $-y$-direction in Figure 3.

Example Response

Magnetic Field from Wire 2 at Point P

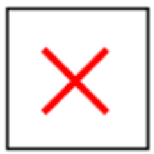


Figure 2

Magnetic Force on Wire 1 by Wire 2

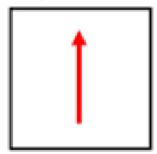


Figure 3

(ii) For a multistep derivation that includes $B = \frac{\mu_0 I}{2\pi r}$, $\sum \vec{F} = 0$, an equation that is equivalent to one of the equations listed, or a relevant equation — **Point A3**

Scoring Note: Vector notation is not required for this point to be earned.

For a correct expression for the magnitude of the magnetic field due to the current in Wire 2 along Wire 1 (e.g., $B_2 = \frac{\mu_0 I}{2\pi d}$) — **Point A4**

For a substitution of $2I$ for a current term in **one** of the following expressions: — **Point A5**

- The magnitude of the magnetic field due to the current in Wire 3 along Wire 1 (e.g., $\frac{\mu_0 (2I)}{2\pi d_3}$)
- The magnitude of the magnetic force exerted on Wire 1 due to the current in Wire 3 (e.g., $I\ell \frac{\mu_0 (2I)}{2\pi d_3}$)

For equating the magnitudes of the magnetic fields from or the force per unit length exerted by the currents in wires 2 and 3 along Wire 1, consistent with point A5 (e.g., $\frac{\mu_0 I}{2\pi d} = \frac{\mu_0 (2I)}{2\pi d_3}$) — **Point A6**

For a correct expression for $|y_3|$ (e.g., $|y_3| = 2d$) — **Point A7**

Scoring Note: A correct, isolated, final expression earns points A4, A5, A6, and A7.