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.

Example Response

$$B = \frac{\mu_0 I}{2\pi r}$$

$$B_2 = \frac{\mu_0 I}{2\pi d}$$
$$B_3 = \frac{\mu_0 (2I)}{2\pi d_3}$$

$$B_2 = B_3$$
$$\frac{\mu_0 I}{2\pi d} = \frac{\mu_0 (2I)}{2\pi d_3}$$
$$d_3 = 2d$$

$$y_3 = -2d$$

B

For indicating that the induced current in the loop is clockwise — **Point B1**

For indicating **one** of the following: — **Point B2**

- The direction of the magnetic field due to the currents in wires 1 and 2 is into the page inside the loop.
- The magnetic flux through the loop due to the currents in wires 1 and 2 is into the page.

For correctly relating the change in the absolute value of the magnetic flux to the direction of the induced magnetic field produced by the induced current in the loop — **Point B3**

Scoring Note: This point is checking for a correct application of Lenz's law to the direction of the magnetic field chosen in point B2.

Example Response

Clockwise. The magnetic field from wires 1 and 2 is directed into the page within the loop, and the absolute value of the magnetic flux through the loop decreases as the loop moves away from the wires. This means that the induced magnetic field produced by the induced current in the loop must also be into the page.