1. Each of the problems in this part has a description of an object and an optical device (lens or mirror). A sketch is shown below. For each case, specify whether

- the image is real (R), virtual (V), or no image is formed (N);
- the image is on the same side of the device as the object (S) or the opposite side (O). If there is no image put a null mark (φ);
- if an image is formed, on which side of the system must the observer be in order to see it, left (-) or right (+)?

For each problem you should therefore give three answers (for example : V O +). For the mirrors the center is shown. For the lenses, the focal points are shown. The radius of curvature of the mirrors is R, the focal length of the lenses is f. (6 pts each, 2 for each answer)

a. An object on the right side of a spherical mirror, a distance s > R from the mirror. The mirror is concave towards the object. [RS+]
b. An object on the right side of a spherical mirror, a distance s < R/2 from the mirror. The mirror is convex towards the object. [VO+]
c. An object on the left side of a spherical mirror, a distance R > s > R/2 from the mirror. The mirror is concave towards the object. [RS-]
d. An object on the right side of a convex lens, a distance s > f from the lens. [RO-]
e. An object on the left side of a convex lens, a distance s < f from the lens. [VS+]

For each of the cases the rays showing where the image is formed are sketched on the diagram below.

2. The figure at the left below shows a cross section of four long parallel wires (labeled A through D) taken in a plane perpendicular to the wires. One or more of the wires may be carrying a current. If a wire carries a current it is in the direction indicated and has magnitude I₀.

For each of the four vector quantities (i) through (iv) give the direction of the quantity. To indicate the direction, use one of the letters associated with a directional arrow on the "compass" figure at the right below. If the magnitude of the quantity is zero, write "0". If it is non-zero, but in none of the indicated directions, write "Other".

i. Only wires A and C are carrying current. What is the direction of the force on wire D? [0]

ii. Only wires B and D are carrying current. What is the direction of the force on wire D? [E]

iii. Only wire B is carrying current. What is the direction of the force felt by an electron at point E traveling in the A direction (on the compass)? [K] (+3 for J)

iv. Only wires B and D are carrying current. What is the direction of the force felt by an electron at point E traveling in the C direction (on the compass)? [0]
3. (10 points) In the picture shown at the right is shown the women’s march held in Washington DC last Sunday. Estimate the number of people visible in the picture. Be sure to clearly state your assumptions and how you came to the numbers you estimated, since grading on this problem will be mostly based on your reasoning, not on your answer.

There are a variety of ways to do the estimate. The simplest is to note that the tiny figures near the open space at the lower right are people. Assuming they are about 6 ft tall, we can estimate the distance across the bottom to be about 500 ft across. The mall down to the capitol is about 5 times as long as this (keeping in mind that the picture shows perspective, so the figure filled with people is actually a rectangle, not a rhombus). This makes the area about (500 ft) x (2500 ft) ~ 1.25 x 10^6 ft^2. Another way to get this is to say that the mall is about 2 city blocks across and that there are about 20 city blocks to the mile. Another way is to remember walking the mall and how much time it took you. (4 pts for estimate of area)

Next we have to decide how much space a person takes when packed in tightly. I’m a bit less than two feet from shoulder to shoulder, using my handspan to measure. So a reasonable high density estimate might be 3 ft x 2 ft or 6 ft^2. (3 pts for estimate of space taken up by a person)

Putting these together, the number of people is about the area / amount of area each person takes up or (1.25 x 10^6 ft^2) / (6 ft^2) ~ 200,000 in the picture (3 for correct calculation).

4. In our tutorial working with mirrors, two students, Ethelred and Guinivere, answered the question, “Where does the image [in the mirror] appear to be located?” by saying “On the mirror.” Do you agree with them or not? If you disagree, where would you say the image is and how would you justify your answer to them? If you agree, propose different plausible position for the image in the mirror and explain why you prefer Ethelred and Guinivere’s answer.

I disagree with E&G. There are lots of ways your brain decides where something is. If you know something is a mirror, one part of you knows that the light and therefore the image is coming from the mirror. But the automatic part of your vision doesn’t know about mirrors. It just responds to what you see. If the mirror were in a slightly dark place or placed so you didn’t realize it was a mirror at first, you would assume it was a window and that the objects you see in it were not on the window but behind it on the other side. To decide where this part of our brain sees the image in the mirror, we can point at it from two different directions (the Mel and Taylor technique) and see at what point those directions intersect. This is what our two eyes do to help us decide on the position of objects. If we were to do this, we would see that the image lies behind the mirror, the same distance behind as the object is in front (along a perpendicular drawn from the object to the mirror.)

(If only 1 direction is used but a second is not included to determine location, -4. If a description of the technique is presented without an explanation of why this technique works, -3.)

5. In lecture, we did a demonstration in which a curved mirror was used to project a real image of a lit bulb (upside down and hidden from class view by a box) on top of a lit bulb (rightside up and on top of the box).

(a) Where do you have to place the box in order to have the image appear right on top of the unlit bulb? The focal length of the mirror is 10 cm. The box with the bulbs is shown at the right in the figure below, ready to be slid to the left to the appropriate position. (10 pts)
The position of the object and the position of the image are related by the equation
\[
\frac{1}{f} = \frac{1}{o} + \frac{1}{i} \quad (3 \text{ pts})
\]

If we want to put the object so that the image is at the same distance from the mirror as the object, then we need to have \( i = o \). (3 pts)

This yields the result
\[
\frac{1}{f} = \frac{1}{o} + \frac{1}{o} = 2
\]
\[
f = \frac{o}{2}
\]
\[
o = 2f
\]

So we have to put the object at 20 cm. (2 pts for putting right numbers in right places, 2 for answer)

(b) How big will the image of the lit bulb be compared to the size of the lit bulb? That is, how big should we make the unlit bulb so that it is the same size as the image of the lit bulb? (10 pts)

The size of the object is determined by the magnification equation
\[
m = \frac{h'}{h} = \frac{i}{o} \quad (3 \text{ pts})
\]

Since we want the object and image the same distance from the mirror, we have \( i = o \) so
\[
\frac{h'}{h} = \frac{o}{o} = 1
\]

so the object and image will be the same size. (4 for reasoning, 1 for answer)

(c) On the figure below, sketch the correct position of the lit bulb and draw a ray diagram to confirm your calculation. (10 pts)

Moving the object to a position 20 cm from the mirror, as required by the calculation above, gives the figure shown. Drawing two rays from the top of the lit bulb, we see they image at the top of the unlit bulb. The unlit bulb will therefore be filled with images of lit points from the lit bulb, and the unlit bulb will give off light in exactly the same way it would as if it had been lit. (each correct ray 2 pts for first two rays, correct image 6)