1. A penguin waddles along the optical axis of a concave mirror starting from a position that is greater than twice the focal length and keeps walking until it almost touches the concave mirror.

   (a) As the penguin walks, when does it see a larger, upright image of itself? Pick one:
   (Note: f is the focal length. Drawing ray-tracing diagrams may be helpful, although you are not required to draw/use them.)
   Option 1: When it is $> 2f$ from the mirror
   Option 2: When it is between $2f$ and f from the mirror
   Option 3: When it is less than f from the mirror

   * Solve problem using ray tracing diagrams for each three options, showing the object, two rays, and the resulting image.

2. Antireflection coatings are used in solar cells to maximize the amount of light that the semiconductor layer of the cell absorbs. Light is reflected off the semiconductor surface, so you want a reflective coating on top of it such that the light reflected at the air/coating interface is completely out of phase (destructively interferes) with the outgoing light that was reflected at the coating/semiconductor interface. This results in more light being transmitted into the semiconductor instead of back out into the air. Note that the materials have indices of refraction n_1 and n_2 such that $n_1 < n_2$. The situation is depicted in Figure 1.

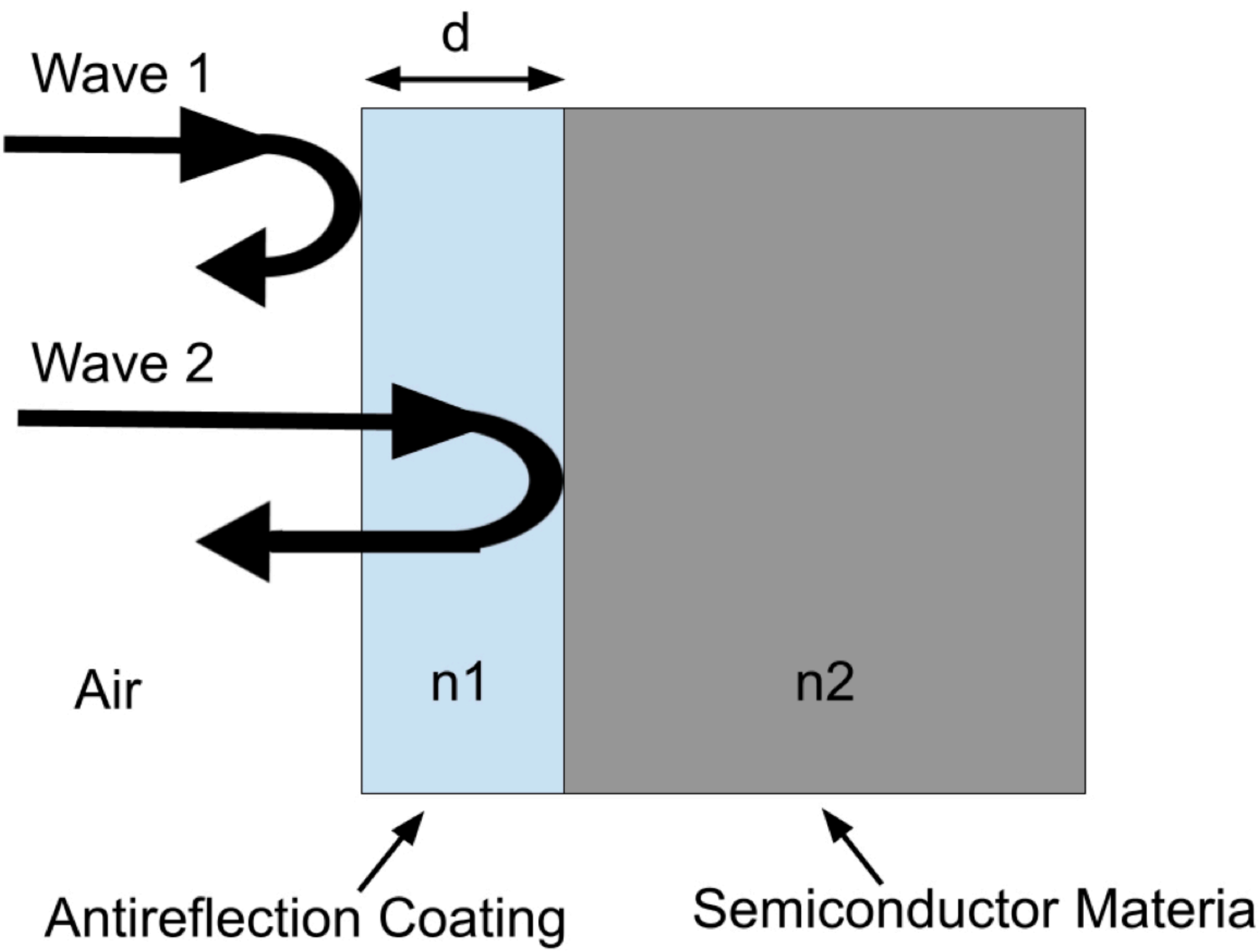

Figure 1

(a) When light reflects from the air and antireflecive coating interface, is there a phase change of π? Note: a phase change of π is the same as a phase change of 180° or $\frac{\lambda}{2}$. (*Hint*: How is refractive index related to a phase change upon reflection?)

(b) When light reflects from the antireflective coating and semiconductor material interface, is there a phase change of π?

(c) What is the path length difference between light reflected at the first interface (wave 1) vs. the second interface (wave 2) in terms of antireflection coating thickness d? (In other words, what is the additional distance that wave 2 must travel before it reaches the point that wave 1 was reflected and continues traveling left? Don't overthink this part!)

(d) What is the condition for antireflection coating thickness that results in optimal constructive interference between the two outgoing waves (traveling left) at the air/coating interface? (Write an expression for antireflection coating thickness d in terms of wavelength in air λ, refractive index n_1, and integer m. You can assume normal incidence.)