1. The bending of light as it moves from one medium to another with differing indices of refraction is due to a change in what property of the light?
   A) amplitude
   B) period
   C) frequency
   **D) speed**
   E) color

2. The figure shows the path of a portion of a ray of light as it passes through three different materials. *Note: The figure is drawn to scale.*

![Diagram of light rays passing through three materials](image)

What can be concluded concerning the refractive indices of these three materials?
A) $n_1 < n_2 < n_3$
B) $n_1 > n_2 > n_3$
C) $n_3 < n_1 < n_2$
D) $n_2 < n_1 < n_3$
E) $n_1 < n_3 < n_2$

3. A light ray is traveling in a diamond ($n = 2.419$). If the ray approaches the diamond-air interface, what is the minimum angle of incidence that will result in all of the light being reflected back into the diamond? The index of refraction for air is 1.000.
   A) 24.42°
   B) 32.46°
   C) 54.25°
   D) 65.58°
   E) 77.54°

4. An object is placed 4.0 cm from a thin converging lens with a focal length of 12 cm. Which one of the following statements is true concerning the image?
   A) The image is virtual and 6.0 cm from the lens.
   B) The image is virtual and 12 cm from the lens.
   C) The image is real and 3.0 cm from the lens.
   D) The image is real and 6.0 cm from the lens.
   E) The image is real and 12 cm from the lens.
Use the following to answer question 5.
A 4.0-cm object is placed 30.0 cm from a converging lens that has a focal length of 10.0 cm as shown in the diagram.

![Diagram of a converging lens with object and focal length marked]

Note: The diagram is not drawn to scale.

5. Where is the image located?
   A) 15 cm to the left of the lens
   B) 7.5 cm to the left of the lens
   C) 7.5 cm to the right of the lens
   D) **15 cm to the right of the lens**
   E) 30 cm to the right of the lens

Use the following to answer question 6.
Two converging lenses, each with a focal length of 0.12 m, are used in combination to form an image of an object located 0.36 m to the left of the left lens in the pair. The distance between the lenses is 0.24 m.

6. Where is the final image located relative to the lens on the right?
   A) 0.06 m to the left of the lens
   B) **0.12 m to the left of the lens**
   C) 0.18 m to the left of the lens
   D) 0.12 m to the right of the lens
   E) 0.36 m to the right of the lens

7. Light that is incident upon the eye is refracted several times before it reaches the retina. As light passes through the eye, at which boundary does the majority of the overall refraction occur?
   A) lens/aqueous humor
   B) **air/cornea**
   C) lens/vitreous humor
   D) aqueous humor/iris
   E) vitreous humor/retina
8. In a Young's double slit experiment, the separation between the slits is $1.20 \times 10^{-4}$ m; and the screen is located 3.50 m from the slits. The distance between the central bright fringe and the second-order bright fringe is 0.0415 m. What is the wavelength of the light used in this experiment?
   A) 428 nm  
   B) 474 nm  
   C) 517 nm  
   D) 642 nm  
   **E) 711 nm**

9. A transparent film ($n = 1.4$) is deposited on a glass lens ($n = 1.5$) to form a non-reflective coating. What thickness would prevent reflection of light with wavelength $5.00 \times 10^2$ nm in air?
   A) 89 nm  
   B) 125 nm  
   C) 170 nm  
   D) 250 nm  
   E) 357 nm

10. The Hubble Space Telescope in orbit above the Earth has a 2.4 m circular aperture. The telescope has equipment for detecting ultraviolet light. What is the minimum angular separation between two objects that the Hubble Space Telescope can resolve in ultraviolet light of wavelength 95 nm?
   A) $4.8 \times 10^{-8}$ rad  
   B) $7.0 \times 10^{-8}$ rad  
   C) $1.9 \times 10^{-7}$ rad  
   D) $1.5 \times 10^{-7}$ rad  
   E) $3.3 \times 10^{-9}$ rad

11. In a science fiction novel, a starship takes three days to travel between two distant space stations according to its own clocks. Instruments on one of the space stations indicate that the trip took four days. How fast did the starship travel, relative to the space station?
   A) $1.98 \times 10^8$ m/s  
   B) $2.24 \times 10^8$ m/s  
   C) $2.51 \times 10^8$ m/s  
   D) $2.83 \times 10^8$ m/s  
   E) $2.99 \times 10^8$ m/s
12. A spaceship traveling at 0.8550c relative to the Earth monitors a motorcycle drag race on Earth. The space travelers measure the time from the start to the finish of the race to be 14.46 s. What is the proper time interval for the motorcycle race?

A) 7.499 s
B) 8.348 s
C) 10.22 s
D) 14.46 s
E) 27.90 s

13. A meter stick is observed to be only 0.900 meters long to an inertial observer. At what speed, relative to the observer, must the meter stick be moving?

A) $0.44 \times 10^8$ m/s
B) $0.57 \times 10^8$ m/s
C) $0.95 \times 10^8$ m/s
D) $1.31 \times 10^8$ m/s
E) $2.70 \times 10^8$ m/s

14. Determine the total energy of an electron traveling at 0.98c.

A) 0.25 MeV
B) 0.51 MeV
C) 0.76 MeV
D) 1.8 MeV
E) 2.6 MeV

15. The average power output of a nuclear power plant is $5.00 \times 10^2$ MW. In one minute, what is the change in the mass of the nuclear fuel due to the energy being taken from the reactor? Assume 100% efficiency.

A) $9.3 \times 10^{-17}$ kg
B) $9.3 \times 10^{-11}$ kg
C) $3.3 \times 10^{-13}$ kg
D) $3.3 \times 10^{-7}$ kg
E) 9.3 kg
16. Two rockets, A and B, travel toward each other with speeds 0.5c relative to an inertial observer.

Determine the speed of rocket A relative to rocket B.
A) 0.2c
B) 0.4c
C) 0.6c
D) 0.8c
E) c

17. Complete the following statement: The results of special relativity indicate that
    A) Newtonian mechanics is a valid approximation at low speeds \((v << c)\).
    B) the laws of electromagnetism are invalid at speeds that are comparable to that of light.
    C) Newtonian mechanics is an incorrect theory.
    D) moving clocks run fast compared to when they are at rest.
    E) moving objects appear to be longer than when they are at rest.

18. A laser produces 3.0 W of light at wavelength 600 nm. How many photons per second are produced?
    A) \(7.3 \times 10^{15}\)
    B) \(4.2 \times 10^{17}\)
    C) \(1.0 \times 10^{17}\)
    D) \(3.0 \times 10^{18}\)
    E) \(9.1 \times 10^{18}\)
19. The graph shows the variation in radiation intensity per unit wavelength versus wavelength for a perfect blackbody at temperature $T$. Complete the following statement: As the blackbody temperature is increased, the peak in intensity of this curve

A) will remain constant.
B) will be shifted to longer wavelengths and its magnitude will increase.
C) will be shifted to shorter wavelengths and its magnitude will increase.
D) will be shifted to longer wavelengths and its magnitude will decrease.
E) will be shifted to shorter wavelengths and its magnitude will decrease.

20. Complete the following statement: The photon description of light is necessary to explain
A) polarization
B) photoelectric effect
C) diffraction of light
D) electron diffraction
E) interference of light

21. In the Compton effect, a photon of wavelength $\lambda$ and frequency $f$ hits an electron that is initially at rest. Which one of the following occurs as a result of the collision?
A) The photon is absorbed completely.
B) The photon gains energy, so the final photon has a frequency greater than $f$.
C) The photon gains energy, so the final photon has a wavelength greater than $\lambda$.
D) The photon loses energy, so the final photon has a frequency less than $f$.
E) The photon loses energy, so the final photon has a wavelength less than $\lambda$.

22. Approximately, what is the de Broglie wavelength of an electron that has been accelerated through a potential difference of 150 V? The mass of an electron is $9.11 \times 10^{-31}$ kg.
A) 0.1 nm
B) 1 nm
C) 10 nm
D) 100 nm
E) 1000 nm
23. Determine the wavelength of incident electromagnetic radiation required to cause an electron transition from the $n = 6$ to the $n = 8$ level in a hydrogen atom.

A) $1.2 \times 10^3$ nm  
B) $2.2 \times 10^3$ nm  
C) $3.4 \times 10^3$ nm  
D) $5.9 \times 10^3$ nm  
E) $7.5 \times 10^3$ nm

24. An electron is in the ground state of a hydrogen atom. A photon is absorbed by the atom and the electron is excited to the $n = 4$ state. What is the energy in eV of the photon?

A) 13.6 eV  
B) 12.8 eV  
C) 12.1 eV  
D) 10.2 eV  
E) 0.85 eV