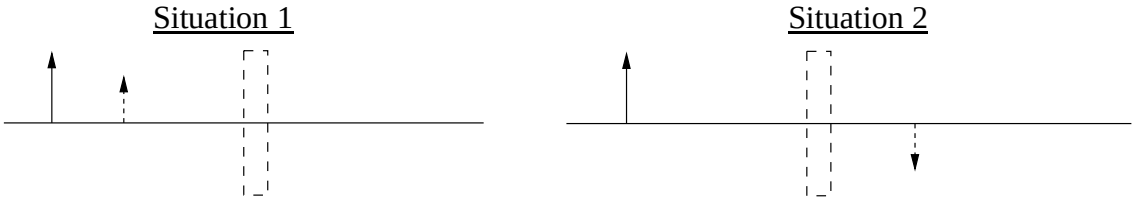
1. Newton's Laws provide a good description of the flight of a baseball because:

A) Its speed is small compared to *c* and its size is large compared to atomic scales.
B) Planck's constant is nonzero.
C) The earth is an inertial reference frame.
D) Quantum mechanics and relativity cannot be applied to baseballs.
E) The Compton wavelength of a baseball is large compared to atomic scales.

2. In the two figures below, the solid arrow represents the object, and the dashed arrow represents the image. The dashed rectangle represents a lens.



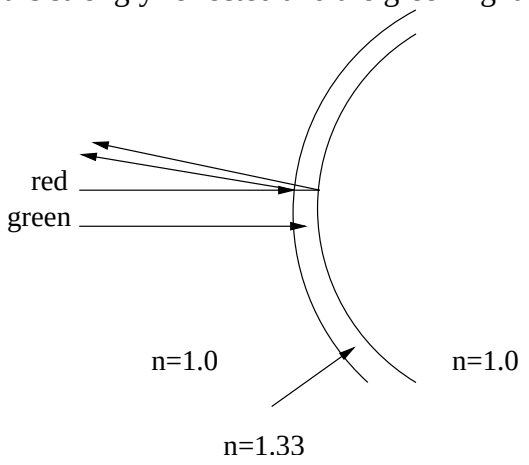
In situation 1 and 2, the lenses are respectively:

A) diverging, diverging.
B) converging, converging.
C) diverging, converging.
D) converging, diverging.
E) impossible to determine.

3. A red laser pointer has a wavelength of 650 nm. The laser light emerges from a pupil with a diameter of 3.2 mm. What is the width of the spot when the laser is pointed at a screen 18 m away?

A) 4.5 mm B) 7.3 mm C) 8.9 mm D) 3.2 mm E) 6.0 mm

4. A soap bubble is illuminated by a combination of red light (λ=736 nm) and green light (λ=552 nm). The red light is strongly reflected and the green light is strongly absorbed.



What is the minimum thickness of the bubble?

A) 138 nm B) 415 nm C) 552 nm D) 622 nm E) 276 nm

5. The muon is an elementary particle with the same charge as the electron, but its mass is 206 times larger. Suppose that a muon and a proton come together to form a "muonic hydrogen atom". If the ionization energy of an ordinary hydrogen atom is 13.6 eV, what is the ionization energy of muonic hydrogen?

A) 2800 eV B) 0.95 eV C) 0.066 eV D) 195 eV E) 13.6 eV

Problems 6 and 7 refer to the following situation. A sheet of clean, photosensitive metal with work function ϕ_0 is illuminated by light with intensity I_0 and wavelength λ_0. When this happens, electrons are ejected from the surface at a rate R_0 electrons per second. You observe that the most energetic of these electrons have a kinetic energy of KE_0.

6. If the intensity of the incident light is increased, electrons now leave the surface at rate R' and with maximum kinetic energy KE′. Which statement is true?

A) $R' > R_0$ and $KE' > KE_0$.
B) $R' > R_0$ and $KE' < KE_0$.
C) $R' = R_0$ and $KE' > KE_0$.
D) $R' < R_0$ and $KE' = KE_0$.
E) $R' > R_0$ and $KE' = KE_0$.

7. Which of the following changes to the experiment would cause the maximum kinetic energy of the electrons to <u>increase</u>? (For each choice, assume all the other parameters of the experiment remain constant.)

A) Increase the light intensity to $2I_0$.
B) Increase the wavelength to $2\lambda_0$.
C) Decrease the wavelength to $\lambda_0/2$.
D) Choose a metal with a larger work function.
E) None of these.

8. In Bohr's model of the hydrogen atom, the allowed energy levels are $E_n = -(13.6\text{ eV})/n^2$, where n is the principal quantum number. If a hydrogen atom undergoes a transition from the $n=4$ to the $n=3$ state, it will:

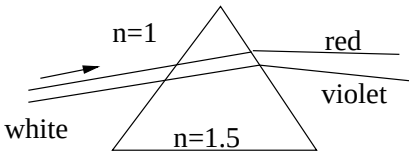
A) emit a 0.85 eV photon.
B) emit a 0.66 eV photon.
C) absorb 1.51 eV of energy.
D) emit a 1.51 eV photon.
E) absorb 0.66 eV of energy.

9. On February 1, 2003, the space shuttle *Columbia* disintegrated upon re-entry to the Earth's atmosphere, killing its crew of seven astronauts. Flight engineers immediately suspected that the tragedy was caused by damaged heat-resistant tiles on the left wing, which had been struck by a piece of debris during liftoff. NASA was subsequently criticized for failing to use spy satellites to photograph the shuttle while it was still in orbit, to try to determine the extent of the damage. Suppose that the damaged area of the wing was roughly 30 cm in diameter. What is the greatest distance at which a spy satellite with a 1.2 m diameter lens could detect the damage? Assume that the photograph would be taken in yellow light (the peak of the solar spectrum), with a wavelength of 580 nm.

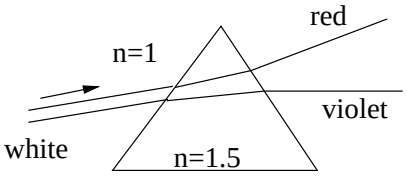
A) 600 km B) 430 km C) 310 km D) 510 km E) 850 km

10. Which of the following figures most accurately depicts the passage of white light through a prism?

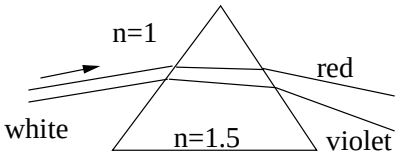
A)



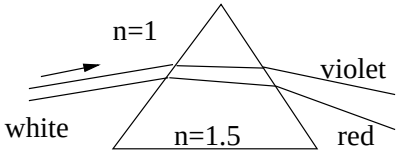
B)



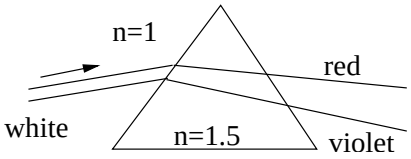
C)



D)



E)



11. Captain Kirk and his crew are cruising around the galaxy in the *USS Enterprise* at a constant speed of Warp Factor 5. They report that they have been maintaining this speed for 48 days. During this time, 76 days have elapsed on earth. How fast is Warp Factor 5?

A) 0.70*c* B) 0.91*c* C) 0.61*c* D) 0.78*c* E) 0.82*c*

12. A famous problem that helped lead to the development of quantum mechanics was the so-called "ultraviolet catastrophe." The "catastrophe" refers to the failure of classical physics to explain what phenomenon?

A) The photoelectric effect.
B) Electron diffraction.
C) Young's double-slit experiment.
D) Compton scattering.
E) The spectrum of hot, glowing objects.

13. Without her contact lenses, a student reports that she cannot see objects clearly if they are less than 65 cm away. What should be the refractive power of her contact lenses (in diopters) in order for her to see objects as close as 25 cm away?

A) 2.5 B) 5.5 C) -2.5 D) -5.5 E) 1.1

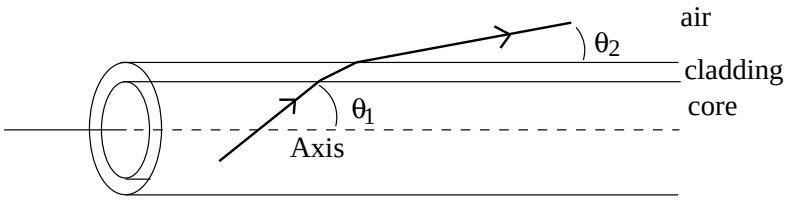
14. A sharpshooter is taking aim at the center of a target. He fires the bullet from his rifle, which of course has a circular aperture through which the bullet exits the rifle. Unfortunately, he misses the bullseye. He claims this happened because diffraction changed the path of the bullet. Is this a plausible explanation?

A) Yes.
B) No, because the de Broglie wavelength of the bullet is too small.
C) No, because the velocity of the bullet is much less than *c*.
D) No, because the diameter of the aperture is too small.
E) No, because only a rectangular slit could cause diffraction.

15. The Compton scattering formula is $\lambda - \lambda' = \frac{h}{m_e c}(1 - \cos\theta)$. In this expression, θ is

A) The angle between the incident photon and the scattered electron.
B) The angle between the scattered photon and the scattered electron.
C) Equal to $n\lambda / D$, where *n* is an integer.
D) The angle to the first minimum.
E) The angle between the incident photon and the scattered photon.

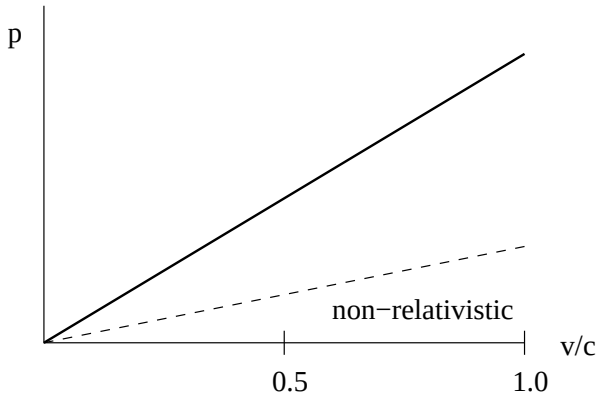
16. A light ray in the core (*n*=1.40) of an optical fiber travels at an angle of θ_1=49° with respect to the axis of the fiber. The ray is transmitted through the cladding (*n*=1.20) and into the air. What angle θ_2 does the exiting ray make with respect to the outside surface of the cladding?



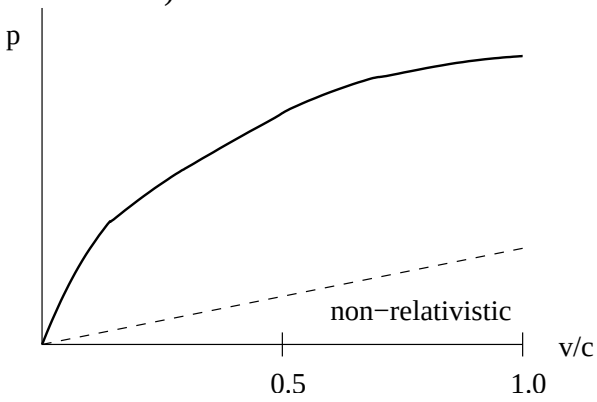
A) 35° B) 8° C) 23° D) 13° E) 40°

17. In the graphs below, the dashed line shows the nonrelativistic momentum for a certain particle as a function of its velocity. (Since the nonrelativistic momentum is *mv*, the graph is a straight line.) In which graph does the solid line best represent the relativistic momentum for this particle?

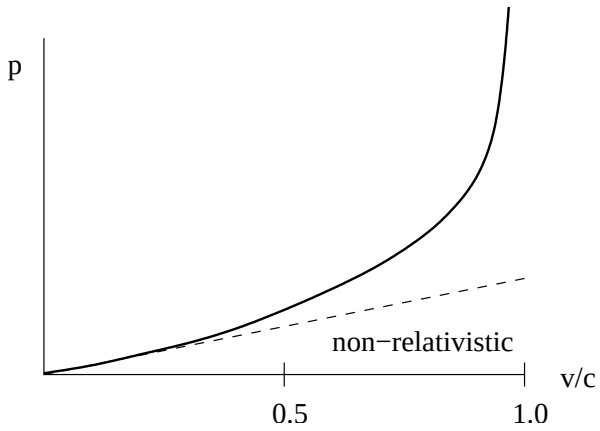
A)



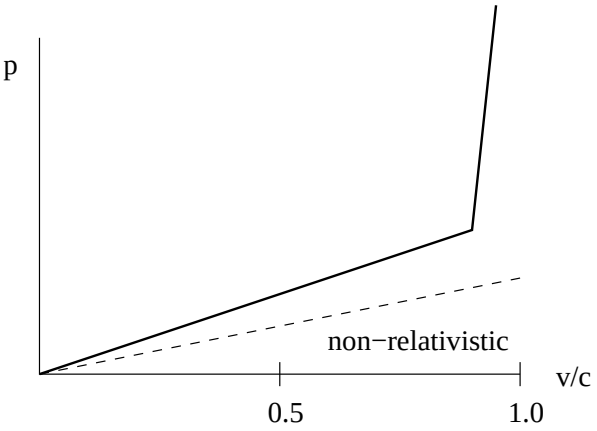
B)



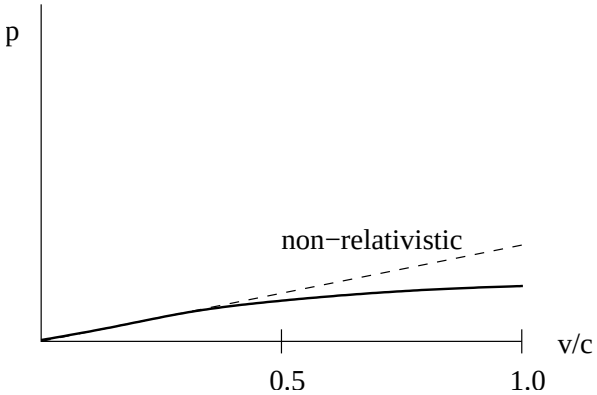
C)



D)



E)



18. A "standard" 35mm slide measures 24.0 mm by 36.0 mm. Suppose a slide projector produces a 60.0 cm by 90.0 cm image of the slide on a screen. The focal length of the lens is 12.0 cm. How far from the lens is the screen?

A) 2.04 m B) 3.78 m C) 3.00 m D) 3.12 m E) 4.64 m

19. A beam of monochromatic laser light passes through a diffraction grating with 500 lines/cm. When the light strikes a screen 12 m away, the first-order maximum is 33 cm away from the central bright spot. What is the wavelength of the light?

A) 550 nm B) 533 nm C) 455 nm D) 600 nm E) 500 nm

20. The α particles used by Geiger and Marsden to study the nucleus had kinetic energy E and mass m. The speed of the particles was much less than c. What was the de Broglie wavelength of these particles?

A) $\frac{hc}{E}$ B) $\frac{h}{mc}$ C) $\frac{h}{\sqrt{4\pi\epsilon_0 mE}}$ D) $\frac{hE}{2m}$ E) $\frac{h}{\sqrt{2mE}}$

Do not worry about your troubles with mathematics;
I can assure you that mine are still greater.

--Albert Einstein

END OF EXAM

Before you go:

1. Check your work carefully. Make sure you have transferred all your answers to your scantron.
2. **BE SURE YOU HAVE FILLED IN YOUR NAME, SECTION, UM-ID, AND EXAM VERSION NUMBER ON YOUR SCANTRON.** Failure to do these things correctly can result in your grade being delayed or incorrect.
3. Turn in your exam and your scantron at the front of the room. Exams will be returned to you in your discussion section on Tuesday. Solutions to this exam will be posted on the course web page by Monday.