Conceptual Physics **NAME:**

Homework 6a: Properties of Light: Homeworks are due usually a day after the corresponding textbook part/lecture is completed. Due dates will be announced in class. Multiple-choice problems will all be marked. **USE** the answer table for these problems. The rest of the homeworks will be marked for apparent completeness and some full-answer problems will/may be marked in detail. Make the full-answer solutions sufficiently detailed that the grader can follow your reasoning. Solutions will be posted eventually after the due dates. The solutions are intended to be (but not necessarily are) super-perfect and often go beyond full answers. For an argument or discussion problem, there really is no single right answer. The instructor's answer reflects his long experience in physics, but there could be objections to his arguments, assumptions, nuances, style, facts, etc.

NAME:

Answer Table for the Multiple-Choice Questions

	a	b	c	d	e		a	b	c	d	e
1.	O	O	O	O	O	26.	O	O	O	O	O
2.	O	O	O	O	O	27.	O	O	O	O	O
3.	O	O	O	O	O	28.	O	O	O	O	O
4.	O	O	O	O	O	29.	O	O	O	O	O
5.	O	O	O	O	O	30.	O	O	O	O	O
6.	O	O	O	O	O	31.	O	O	O	O	O
7.	O	O	O	O	O	32.	O	O	O	O	O
8.	O	O	O	O	O	33.	O	O	O	O	O
9.	O	O	O	O	O	34.	O	O	O	O	O
10.	O	O	O	O	O	35.	O	O	O	O	O
11.	O	O	O	O	O	36.	O	O	O	O	O
12.	O	O	O	O	O	37.	O	O	O	O	O
13.	O	O	O	O	O	38.	O	O	O	O	O
14.	O	O	O	O	O	39.	O	O	O	O	O
15.	O	O	O	O	O	40.	O	O	O	O	O
16.	O	O	O	O	O	41.	O	O	O	O	O
17.	O	O	O	O	O	42.	O	O	O	O	O
18.	O	O	O	O	O	43.	O	O	O	O	O
19.	O	O	O	O	O	44.	O	O	O	O	O
20.	O	O	O	O	O	45.	O	O	O	O	O
21.	O	O	O	O	O	46.	O	O	O	O	O
22.	O	O	O	O	O	47.	O	O	O	O	O
23.	O	O	O	O	O	48.	O	O	O	O	O
24.	O	O	O	O	O	49.	O	O	O	O	O
25.	O	O	O	O	O	50.	O	O	O	O	O

1. "Let's play *Jeopardy*! For \$100, the answer is: The word has two meaning which must be distinguished by context as usual:

   i) Visible light to which our eyes are sensitive.

   ii) The whole range of electromagnetic radiation which is called the electromagnetic spectrum."

   What is ____________, Alex?

   a) sound b) radio c) a wave phenomenon d) the ether e) light

2. "Let's play *Jeopardy*! For \$100, the answer is: He/she discovered the first form of non-visible light (infrared light) 1800feb11."

   Who is ____________, Alex?

   a) Ben Franklin (1706–1790) b) Émilie du Châtelet (1706–1749)
   c) William Herschel (1738–1822) d) Caroline Herschel (1750–1848)
   e) Thomas Young (1773–1829)

3. Which of the following property of light was **NOT** known since prehistory?

   a) ray-like propagation b) wave propagation c) reflection d) refraction
   e) production by hot sources

4. The systematic study of light to establish general principles and results from those principles began (insofar as we know—which usually goes without saying) with the ancient:

   a) Sumerians, notably Utnapishtim (time of the Flood) and Gilgamesh (26 century BCE).
   b) Egyptians, notably Hatshepsut (1508–1458 BCE) and Akhenaten (14th century BCE).
   c) ancient Greeks, notably Euclid (fl. 300 BCE)and Ptolemy (c. 90–c. 170).
   d) Assyrians, notably Sennacherib (c. 730–681 BCE)
   e) Mayans, notably Sun god Kinich Ahau (eternal)

5. In regard to the science of light, medieval Islamic scientists

   a) made no progress. b) made some progress. c) regressed. d) discovered the telescope.
   e) invented eyeglasses.

6. Isaac Newton (1643–1727) explained light as:

   a) beams of classical particles—but he didn't use the word classical. b) beams of photons.
   c) beams of continuous matter. d) ether waves. e) electromagnetic waves.

7. The wave nature of light was first posited by ____________ and later established as the generally accepted theory by ____________ along with Augustin-Jean Fresnel (1788–1827).

   a) Euclid (fl. 300 BCE); Ptolemy (c. 90–c. 170).
   b) Robert Hooke (1635–1703); Isaac Newton (1643–1727)
   c) Christiaan Huygens (1629–1695); Thomas Young (1773–1829)
   d) Blaise Pascal (1623–1662); Thomas Young (1773–1829)
   e) Émilie du Châtelet (1706–1749); David Rittenhouse (1732–1792)

8. Wave phenomena in many contexts propagate like rays (i.e., beams of continuous matter) if ____________, where λ is wavelength and ℓ is the characteristic size of obstacles or apertures in the path of the waves.

   a) $\lambda/\ell << 1$ b) $\lambda/\ell \gtrsim 1$ c) $\lambda/\ell \approx 1$ d) $\lambda \gtrsim \ell$ e) $\lambda \approx \ell$

9. Visible light (λ in range $400 - -700$ nm) will show ____________ interference and diffraction effects for obstacles of $1\,\mu$m size.

   a) no b) zero c) obvious d) very tiny e) atomic size

10. "Let's play *Jeopardy*! For \$100, the answer is: In the 1860s, he unified electric and magnetic phenomena in what we now call classical electromagnetism. Classical electromagnetism is summarized in 4 equations (i.e., 4 mathematical laws) plus the electromagnetic force formula. The electric and magnetic properties of materials were taken as givens: their explanation required quantum mechanics which was not available before circa 1926. The 4 equations in the absence of charge and current can be reduced to a wave equation

with a phase velocity

$$v = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} ,$$

where ε_0 (vacuum permitivity) and μ_0 (vacuum permeability) are constants determined from electromagnetic phenomena. The numerical value of v was equal within experimental error with the vacuum speed of light. In one of the great eureka moments of history, Prof. X then concluded that light was electromagnetic waves."

Who is ____________, Alex?

a) Lord Kelvin (1824–1907) b) James Clerk Maxwell (1831–1879)
c) Lord Rayleigh (1842–1919) d) Oliver Heaviside (1850–1925)
e) George Francis FitzGerald (1851–1901)

11. Maxwell's equations plus the electromagnetic force law account for all classical electromagnetic phenomena provided one takes the electromagnetic properties of materials as ____________. Quantum mechanics is needed to understand these properties.

    a) classically derivable results b) givens c) takens d) borrows e) nothings

12. From his 4 equations, Maxwell was able to predict that light was:

    a) made of particles that are now called photons.
    b) electromagnetic waves with phase velocity $c = 1/\sqrt{LC}$.
    c) light was electromagnetic waves with phase velocity $c = 1/\sqrt{\mu_0 \varepsilon_0}$.
    d) made of particles that are now called fluxons.
    e) electromagnetic waves with phase velocity $c = \sqrt{T/\mu}$.

13. In Maxwell's day it was already known that there were invisible forms of light (infrared and ultraviolet), but none of these form could be generated by macroscopic oscillations of charge. But one could—although I'm not sure if anyone did—predict that much lower frequency, longer wavelength electromagnetic radiation should exist and could be so generated In 1888, such electromagnetic radiation (which was soon called radio) was discovered by ____________. This was a tremendous verification of Maxwell's equations.

    a) Galileo (1564–1642) b) Isaac Newton (1643–1727) c) James Clark Maxwell (1831–1879)
    d) Heinrich Hertz (1857–1894) e) Albert Einstein (1879–1955)

14. Classical electromagnetism gave a unique value for the phase velocity of electromagnetic radiation. The 19th century scientists assumed this phase velocity was relative to the ____________, a hypothetical medium of oscillation for electromagnetic waves. But velocity was ____________ was rather mysterious since it had no known properties other than being the medium of electromagnetic radiation. A famous attempt (the Michelson-Morley experiment of 1887) to measure the motion relative to the ____________ by detecting changes in the vacuum speed of light gave a null result. This was rather puzzling.

    a) light stuff b) vacuum c) phlogiston d) ether e) either

15. In 1905, Albert Einstein (1879–1955) presented special relativity which posited two axioms: a) the relativity axiom which said the laws of physics should have the same formulae in all inertial frames of reference; b) the vacuum speed of light is the same relativel to all inertial frames. The first axiom was well known; the second seemed bizarre since it violated ordinary notions of relative motions. Classical electromagnetism was alrealy consistent with the two axioms which had seemed to 19th century physicists a sign that it was approximation or that it applied only relative to the ether. Einstein believed classical electromagnetism had to be more fundamental than Newtonian physics and applied in all inertial frames and that no ether existed—electromagnetic waves were oscillations of the electromagnetic field all by itself without any medium required. This guided him in choosing his axioms. The axioms led to many corrections to Newtonian physics and in the results that length and time became frame-dependent quantities. These results have been very well verified, but are only observable with high relative velocities or extremely precise measurments. Special relativity also led to the Einstein equation:

    a) $E = 2mc^2$. b) $E = m/c^2$. c) $E = (1/2)mc^2$. d) $E = mc$. e) $E = mc^2$.

16. Also in 1905, Einstein further developed the idea first introduced by Max Planck in 1900 that light came in packets. These packets are now called ____________ and are understood to be rest-massless

quantum mechanical particles.

a) photons b) lightons c) lichtons d) protons e) electrons

17. Electromagnetic radiation (EMR) is:

a) a **WAVE PHENOMENON**. The EM waves, however, are **NOT EXCITATIONS OF A MEDIUM** as in most other familiar wave phenomena: e.g., sound waves are excitations of air; water waves of water. The EM waves are just self-propagating electromagnetic fields: any description of them as oscillations in a medium has turned out to be physically superfluous: i.e., adds nothing to physical understanding. Of course, EM waves can propagate through media such as air, water, glass, etc. The speed of light **IN VACUUM** is $2.99792458 \times 10^{10}$ cm/s $\approx 3 \times 10^{10}$ cm/s. In matter, the speed of light is always **HIGHER**.
b) a **WAVE PHENOMENON**. The EM waves, however, are **NOT EXCITATIONS OF A MEDIUM** as in most other familiar wave phenomena: e.g., sound waves are excitations of air; water waves of water. The EM waves are just self-propagating electromagnetic fields: any description of them as oscillations in a medium has turned out to be physically superfluous: i.e., adds nothing to physical understanding. Of course, EM waves can propagate through media such as air, water, glass, etc. The speed of light **IN VACUUM** is $2.99792458 \times 10^{10}$ cm/s $\approx 3 \times 10^{10}$ cm/s. In matter, the speed of light is always **LOWER**.
c) a **WAVE PHENOMENON**. The EM waves are excitations of the **ETHER**. The ether permeates all space and has no other effects than as the medium of the EM propagation. Of course, EM waves at the same time as propagating in the ether can also propagate through media such as air, water, glass, etc. The speed of light **IN VACUUM** is $2.99792458 \times 10^{10}$ cm/s $\approx 3 \times 10^{10}$ cm/s. In matter, the speed of light is always **LOWER**.
d) a **WAVE PHENOMENON**. The EM waves are excitations of the **ETHER**. The ether permeates all space and has no other effects than as the medium of the EM propagation. Of course, EM waves at the same time as propagating in the ether can also propagate through media such as air, water, glass, etc. The speed of light **IN VACUUM** is $2.99792458 \times 10^{10}$ cm/s $\approx 3 \times 10^{10}$ cm/s. In matter, the speed of light is always **HIGHER**.
e) a **PARTICLE PHENOMENON** only.

18. In a polarized electromagnetic radiation beam in vacuum, the electric and magnetic field are perpendicular to each other and ____________ the direction of propagation.

a) either are perpendicular to b) neither are perpendicular to c) both are perpendicular to
d) both are aligned with e) are randomly oriented with respect to

19. Electromagnetic waves in vacuum are:

a) oblique. b) transverse waves. c) neither transverse nor longitudinal waves.
d) longitudinal waves. e) both transverse and longitudinal waves.

20. Natural light (which is just a name—there's no unnatural light) has an isotropic distribution of electric and magnetic field vector directions perpendicular to the propagation direction when looked at over space and time though not at one instant and place where, of course, the E-field and B-field vectors can only point in one direction. Light vectors that are not isotropically distributed are ____________ to one degree or another in one way or another.

a) marginalized b) polarized c) metabolized d) pasteurized e) metastasized

21. In wave phenomena, frequency is the number of cycles (i.e., complete oscillations) per unit:

a) cycle. b) pressure. c) energy. d) length. e) time.

22. The MKS unit of frequency is the inverse second (s^{-1}) which is given the special name:

a) freq (Fr). b) hertz (Hz). c) heinrich (Hr). d) insec (I). e) cyclon (C).

23. A well known formula relating frequency, wavelength, and vacuum light speed is:

a) $f\lambda = c$. b) $f/\lambda = c$. c) $\lambda/P = c$. d) $P\lambda = c$. e) $fc = \lambda$.

24. AM radio typically broadcasts at about 1 MHz $= 10^6$ cycles per second. What is the approximate wavelength of this radiation? (Just use the vacuum speed of light $c = 2.99792458 \times 10^{10}$ cm/s for the calculation: it is good enough for the present purpose.)

a) $\sim 3 \times 10^4$ cm = 300 m. b) $\sim 1 \times 10^4$ cm = 100 m. c) $\sim 3 \times 10^{-4}$ cm. d) $\sim 3 \times 10^4$ m.
e) $\sim 3 \times 10^2$ cm = 3 m.

25. "Let's play *Jeopardy*! For $100, the answer is: In modern physics, it is the highest physical speed: i.e., the highest speed at which an effect or information can propagate."

    What is the speed of ____________, Alex?

    a) sound b) thought c) rumor d) light in vacuum
    e) rumor in an information vacuum

26. At fireworks displays, the explosions produce a light flash and sounds.

    a) The sound is heard before the flash is seen.
    b) The flash is seen before the sound is heard.
    c) Sound and flash come simultaneously.
    d) The sound is seen before the flash is heard.
    e) Neither effect is noticed by the spectators.

27. The electromagnetic spectrum is:

    a) the distribution of electromagnetic radiation with respect to temperature.
    b) the spectrum of radiation emitted by a non-reflecting (i.e., blackbody) object at a uniform temperature.
    c) the entire wavelength range of electromagnetic radiation: i.e., the electromagnetic radiation range from zero to infinite wavelength, not counting the limit end points themselves.
    d) the magnetic field of the Sun.
    e) independent of wavelength.

28. As far as we know, electromagnetic radiation can have wavelength (or frequency) anywhere between 0 and infinity. Also as far as we know, the allowed wavelengths form a ____________ like real numbers. It may be that there are no processes to create or destroy electromagnetic radiation above or below a certain wavelength or in some bands, but we do not know of any regions of the electromagnetic spectrum that are absolutley ruled out.

    a) a set of 10^{10}. b) a set of 10^{100}. c) a finite discrete set d) a infinite discrete set
    e) continuum

29. A short list of the bands of the electromagnetic spectrum in order of increasing wavelength is γ ray, X-ray (typical wavelength 1 Å), ultraviolet (UV), visible ($\sim 0.4 - -0.7\,\mu$m):

    a) cyan, indigo, radio. b) infrared red, radio. c) red, radio, infrared.
    d) infrared (IR), microwave (typical wavelength 1 cm), radio.
    e) radio, microwave (typical wavelength 1 cm), infrared (IR).

30. The wavelength range of visible light is about:

    a) 1–20 cm. b) 0.1–10 nm. c) 400–700 nm. d) 700–1000 nm. e) 0.700–1000 microns.

31. Visible light is conventionally divided into:

    a) violet, blue, green, yellow, orange, radio.
    b) X-ray, violet, blue green, yellow, orange, tangerine, red.
    c) Gamma-ray, X-ray, ultraviolet, visible, infrared, microwave, radio.
    d) mauve, navy, forest lawn, goldenrod, tamarind, cerise.
    e) violet, blue, green, yellow, orange, red.

32. Under well lit conditions, humans have ____________ vision and under dim condtions ____________ vision.

    a) phinnish; scottish b) scotopic; photopic c) photopic; scotopic
    d) telescopic; microscopic e) tele; vista

33. Many systems (many macroscopic systems and virtually all molecules, atoms, and nuclei) have natural oscillation or excitation states called ____________. (The term is not used usually for many microscopic excitation states to which it can be applied in principle.) By natural, one means that these systems readily absorb energy and go into the ____________ oscillation or excitation states. Therefore if there

is a force or interaction that can transfer energy to these ____________ oscillation or excitation states, one will often find the system in one of these states. If a force or interaction is not such that can transfer energy to these ____________ oscillation or excitation states, the systems are often relatively unaffected by the force or interaction. The wording of this description is rather intricate in order to be general. There are many special cases that described more simply.

a) eminence/eminences b) resonance/resonances c) prominence/prominences
d) resound/resounds e) redoubt/redoubts

34. The simple pendulum is a pendulum where the bob can be regarded as point mass. The simple pendulum has a single resonance frequency. In the limit of small-amplitude oscillations, the resonance frequency is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\ell}}$$

where g is the graviational field and ℓ is the pendulum length. The period of resonance oscillation is given by:

a) $p = 2\pi\frac{g}{\ell}$. b) $p = 2\pi\frac{\ell}{g}$. c) $p = 2\pi\sqrt{\frac{\ell}{g}}$. d) $p = \frac{1}{2\pi}\sqrt{\frac{\ell}{g}}$. e) $p = 2\pi\sqrt{\frac{g}{\ell}}$.

35. A string held taut between two endpoints has resonances that are standing wave states of transverse waves. In standing wave states, the wave patterns do not propagate, they merely scale up and with time. The resonances exist only at a discrete set of frequencies. Off resonance (i.e., off the resonance frequencies), one has traveling waves. But traveling waves since they are not resonances are rather hard to excite and in many cases nearly cancel and give only relatively small up and down motions in many cases. The half wavelength shapes of a standing wave are called antinodes. A standing wave pattern can only exist when an integer number of antinodes can be fitted between the endpoints. Thus, the conditit. for a standing wave state is

$$n\left(\frac{\lambda}{2}\right) = L ,$$

where $n = 1, 2, 3, \ldots$ is the integer number of antinodes, λ is the wavelength, and L is the string length. The phase velocity v for waves on a string is fixed by the string tension and the string mass per unit length. It follows that the formula resonance frequencies (i.e., the standing wave state frequencies) is:

a) $f = n\left(\frac{v}{2L}\right)$. b) $f = n\left(\frac{2L}{v}\right)$. c) $f = \frac{v}{2Ln}$. d) $f = n\left(\frac{2v}{L}\right)$. e) $f = \frac{v}{Ln}$.

36. In materials, electromagnetic radiation is often absorbed by resonances. Metals are a special case since their free electrons allow strong absorption at any frequency lower than that of X-rays. The electromagnetic radiation energy that goes into a resonance can be dissipated to waste heat or emitted as different frequencies of electromagnetic radiation or emitted at the same frequency of the absorbed electromagnetic radiation. Resonance actually absorb over a band of electromagnetic radiation frequency: sometimes narrow, sometimes broad. Those materials, other than metals, with few or weak resonances in the visible are often ____________ in the visible.

a) prismatic b) red c) luminous d) opaque e) transparent

37. The Canadian flag in ordinary lighting is red and white. When viewed in red light it is:

a) all white. b) red and black. c) all red. d) all black. e) red and white still.