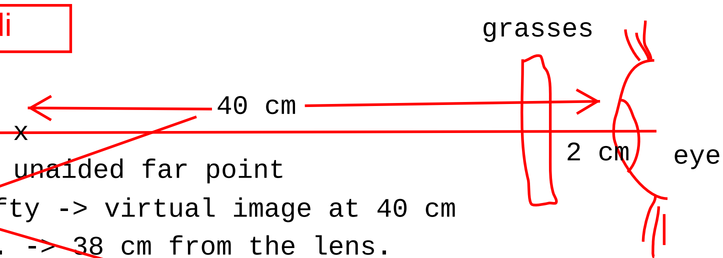
The next two questions pertain to the following situation.

A nearsighted person has a far point of 40 cm unaided. She wears corrective glasses and the lenses are 2 cm in front of her eyes.

The Principle of Correction: place virtual images where you can see clearly.

1. What kind of lenses must she wear so that she can see objects very far away (at ∞) clearly?

1/f = 1/do + 1/di



a. diverging lens
b. converging lens

Objects at infty -> virtual image at 40 cm
FROM the eyes. -> 38 cm from the lens.

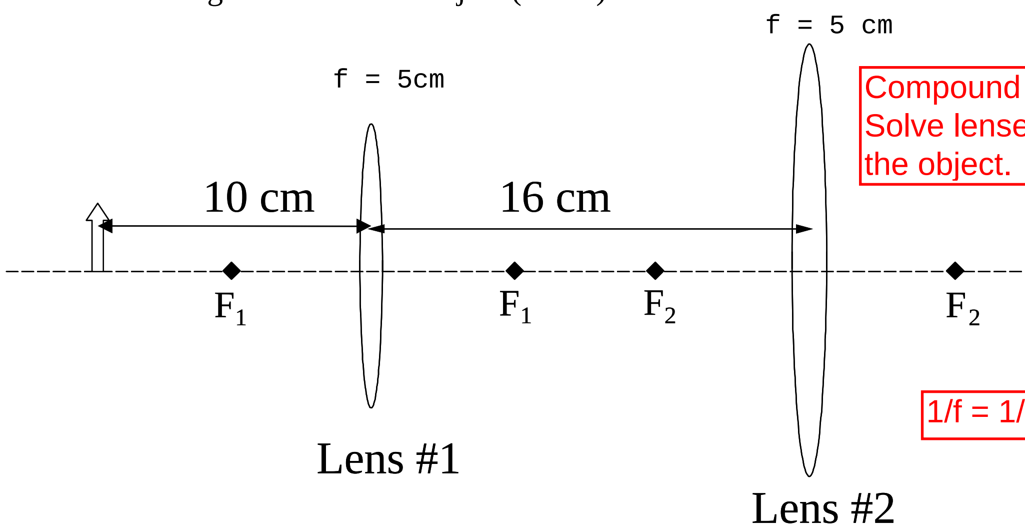
2. What must be the magnitude of the refractive power $|P|$ of the corrective glasses in diopters (1 diopter ≡ 1/m)?

1/f = 1/\infty + 1/(-038)
Therefore, the power is 1/(-0.38) = -2.63 D.

a. 2.63 diopters
b. 1.91 diopters
c. 3.27 diopters

The next three questions pertain to the following situation.

Two lenses are separated by 16 cm. Both Lens #1 and Lens #2 are converging lenses and have a focal length of 5 cm. An object (arrow) is located 10 cm to the left of Lens #1.



Compound lens system
Solve lenses one by one from the object.

1/f = 1/do + 1/di

3. **If lens #2 were not present,** the image formed by lens #1 would be

a. 5 cm to the right of lens #1.
b. 10 cm to the right of lens #1.
c. 15 cm to the right of lens #1.
d. 20 cm to the right of lens #1.
e. 25 cm to the right of lens #1.

```
f = +5
do = +10

1/5 = 1/10 + 1/di  ->  di = 10 real.
```

Bad problem with possible propagation of error.

4. Where is the final image of the **pair of lenses**?

a. 25 cm to the left of lens #2
b. 15 cm to the left of lens #2
c. 10 cm to the left of lens #2
d. 20 cm to the right of lens #2
e. 30 cm to the right of lens #2

```
For the second lens
f = 5 cm
do = 16 -10 = 6cm

1/5 = 1/6 + 1/di -> 1/di = 1/5 - 1/6 = 1/30 real
```

Measure everything relative to the second lens.

5. The final image formed by the **pair of lenses** is

m = -di/do

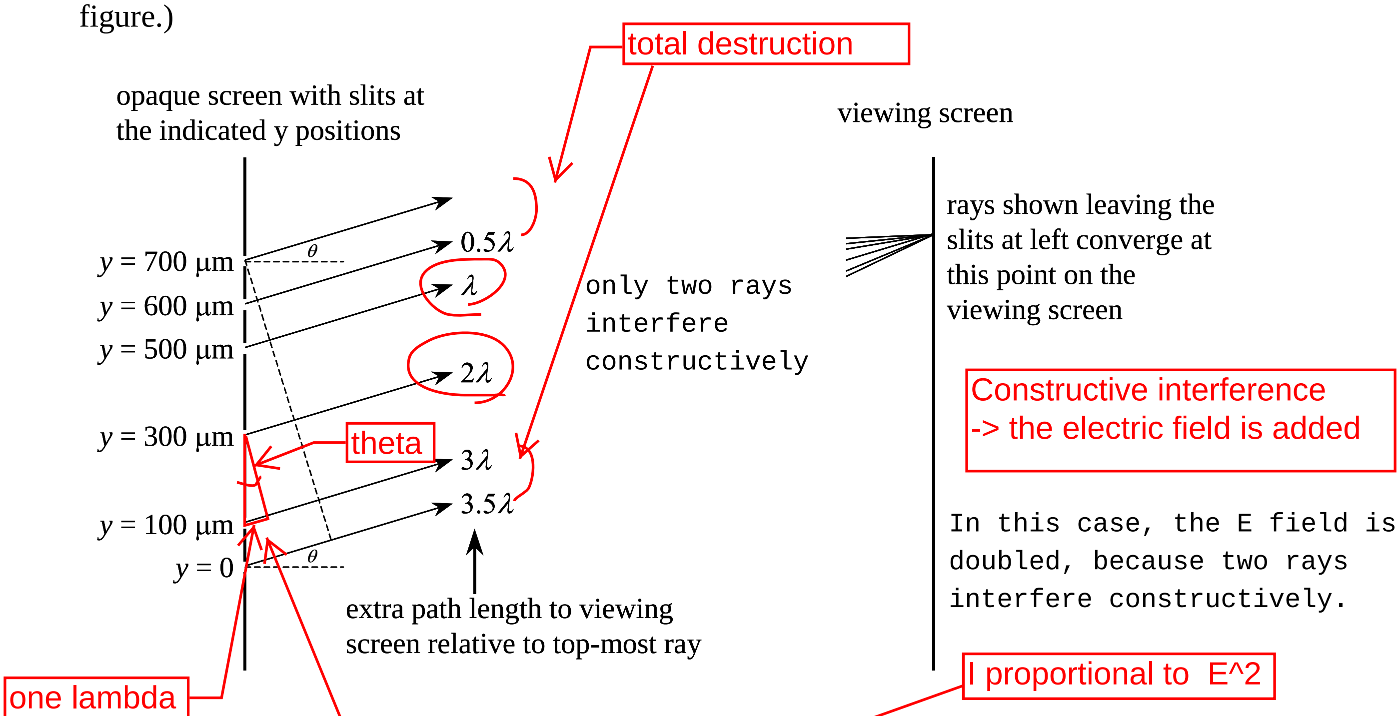
a. inverted relative to the object.
b. upright relative to the object.

```
lens 1: m = -10/10 = -1
lens 2: m = -30/6 = -5
Therefore, the overall (signed) magnification
is 5.  Real, upright.
```

The next two questions pertain to the following situation.

Six slits are cut into an opaque screen as shown in the following figure. The spacing between the slits ***is not uniform;*** the *y* positions of the slits are indicated on the diagram. A viewing screen is positioned several meters to the right of the slits.

The screen is illuminated from the left by a light source of wavelength λ. The particular light rays leaving the slits and converging at one point on the viewing screen are drawn in the diagram. The path lengths from the slits to that point on the screen differ for each of the rays. (The path length differences relative to the top-most ray are shown in the figure.)



6. The ***intensity*** of the light measured at the point of convergence of the rays is I_6. If the intensity of light out of one slit is I_1, what is the ratio of the intensities I_6 / I_1?

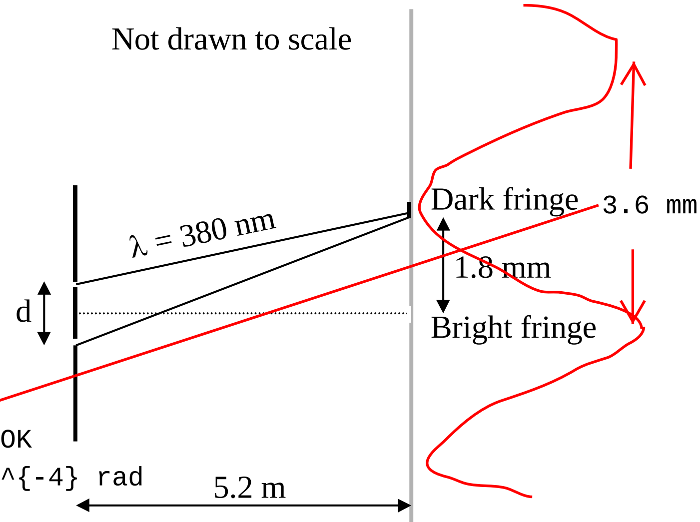
a. $I_6 / I_1 = 0$.
b. $I_6 / I_1 = 2$.
c. $I_6 / I_1 = 4$.
d. $I_6 / I_1 = 9$.
e. $I_6 / I_1 = 36$.

7. Given that the wavelength of light is $\lambda = 650$ nm, determine the angle θ in the figure.

a. 3.25 mrad
b. 6.50 mrad
c. 1.75 mrad

```
Consider this triangle.
200 microm sin theta = lambda
Therefore,
sin theta = 650x10^{-9}/200x10^{-6} = 3.25x10^{-3}.
This is small, so the small angle approximation gives
theta= 3.25x10^{-3} rad.
```

The next three questions pertain to the following situation:



8. Blue light with wavelength $\lambda = 380$ nm is incident upon two narrow slits separated by a distance d before striking a screen 5.2 meters away. The distance between the central bright fringe and first dark fringe is 1.8×10^{-3} m. Calculate d the spacing between the slits. (You may approximate $\sin(\theta) \approx \tan(\theta) \approx \theta$)

a. $d = 0.15$ mm
b. $d = 0.21$ mm
c. $d = 0.36$ mm
d. $d = 0.41$ mm
e. $d = 0.55$ mm

Interference
d sin theta = n lambda
y = L tan theta

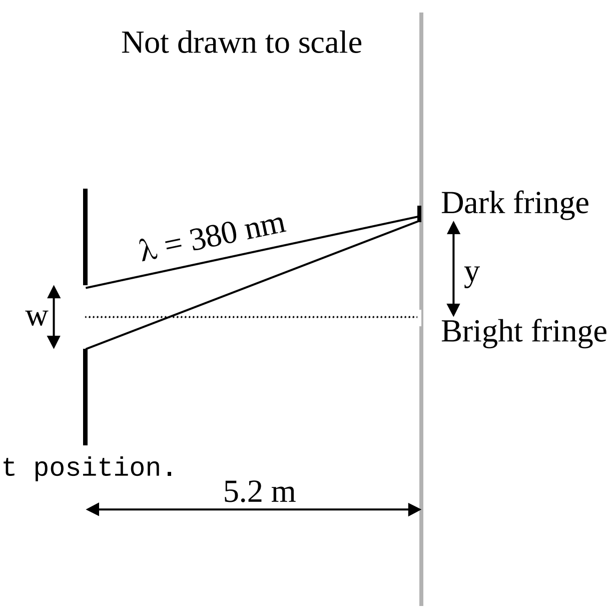
```
Small angle approximation OK
theta = 3.6/5200 = 6.92x10^{-4} rad

d = lambda/theta = 380x10^{-9}/6.92x10^{-4}
  = 54.9x10^{-5}m
```

9. Now red light ($\lambda = 650$ nm) is incident on the same two slits, the distance y between the central bright fringe and the first dark fringe is

a. $y < 1.8$ mm
b. $y = 1.8$ mm
c. $y > 1.8$ mm

Longer wavelength
rays bend more



10. Now the two slits are replaced by a **single slit with width** $w = d$, and illuminated with the original blue light. What is the distance y to the first dark fringe?

a. $y < 1.8$ mm
b. $y = 1.8$ mm
c. $y > 1.8$ mm

diffraction
d sin theta = n lambda
this is dark fringe position

```
y = 3.6 mm must be the first position.
```

This is a problem to trick the students. We should not ask such a question.

The next three questions pertain to the following situation:

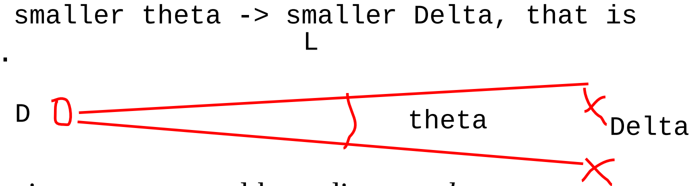
If you go to the Art Institute of Chicago, you can admire paintings by the French painter Georges Seurat. For his work, Seurat uses small dots of color to produce an image. At a distance of a few meters, the eye cannot resolve these dots. You thus see a "smooth" picture.

11. If each dot is the same size, which color dots are the easiest to resolve?

a. Red (λ = 660 nm)
b. Green (λ = 550 nm)
c. Blue (λ = 470 nm)

Resolution
D sin theta = 1.22 lambda

```
Delta = L tan theta
smaller lambda -> smaller theta -> smaller Delta, that is
higher resolution.
```



12. Assume the green (λ = 550 nm) dots in the painting are separated by a distance d = 2.0 mm. What is the maximum distance, L, a person with normal, unaided vision (near point 25 cm, far point infinity, pupil diameter 2.0 mm) can stand from the painting to resolve the individual green dots?

a. L = 1.44 m
b. L = 2.31 m
c. L = 3.27 m
d. L = 4.89 m
e. L = 5.96 m

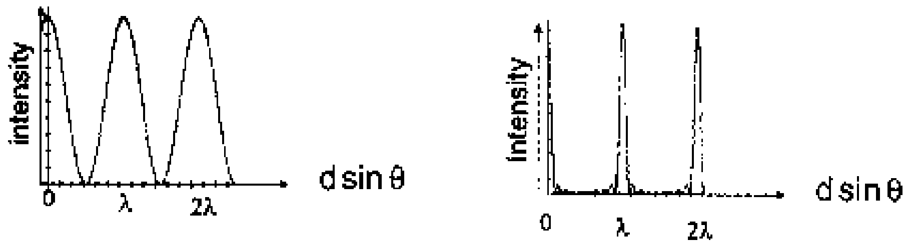
```
Delta = 2x10^{-3} m = d in the problem
D = 2x10^{-3} m

theta = 1.22 lambda/D
L = Delta/theta = D Delta/1.22 lambda
 = 2x10^{-3} x 2x10^{-3}/1.22 550x10^{-9} =0.00596 x 10^{3}
```

13. Let L be the answer to the previous question. If the distance between the green dots were 1.0 mm instead of 2.0 mm, the maximum distance a person with normal, unaided vision (near point 25 cm, far point infinity, pupil diameter 2.0 mm) can stand from the painting to resolve the individual green dots would be

a. smaller than L.
b. equal to L.
c. larger than L.

```
L is proportional to Delta.
```



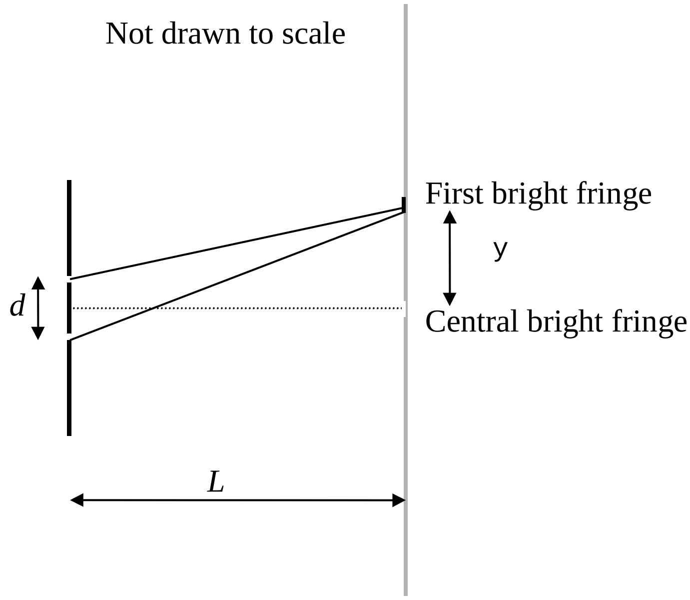
14. Consider a diffraction pattern produced by passing light of wavelength λ through a screen containing a series of equally spaced slits.

True or false: The total number of slits is greater in the pattern on the right than in the pattern on the left.

a. true
b. false

More slits-> sharper fringes

The next two questions pertain to the following situation:



15. An electron beam of energy 2 eV is incident on two slits separated by a distance d = 100 nm. A screen is placed L = 2 m away from the slits. What is the separation between the first interference maximum and the center line? (The mass of the electron is 511 keV/c^2.)

a. 6.5 mm
b. 17.3 mm
c. 36.2 mm

interference d sin theta = n lambda
y = L tan theta

de Broglie wavelength = h/p
KE = p^2/2m

```
lambda = h/\sqrt{2m KE}
= hc/\sqrt{2 x 511x10^3 x 2}
= 1240/1430 = 0.867 nm
theta= lambda/d = 0.867/100
so
y = 2 x 0.867/100
  = 1.73/100 m
```

16. The electron beam is replaced by a beam of light. What energy of photons will recreate the exact same pattern on the screen?

a. 2 eV
b. 350 eV
c. 1.4 keV

The same wavelength 0.867 nm, so 1430 eV.

17. A 2.5 mW laser pointer emits green light of wavelength λ = 530 nm. How many photons does it emit per second?

hf = 1240/ lambda(in nm)

a. 6.7×10^{15} photons/s
b. 3.1×10^{10} photons/s
c. 4.6×10^{14} photons/s

```
photon energy = 1240/530 eV
   = 2.34 eV = 2.34 x 1.6x10^{-19} J
Power = N x photon energy
so
N = 2.410^{-3}/2.34 x 1.6x10^{-19} = 6.68x10^{15}
```

18. In the photoelectric effect, a metal with work function W_0 = 2.8 eV is illuminated by monochromatic light of wavelength λ = 671 nm. If the intensity of the light is increased, which of the following occurs?

max KE = hf - W
one photon -> at most one photoelectron

a. no photoelectrons are emitted
b. the maximum kinetic energy of the photoelectrons increases
c. the work function of the metal decreases

```
hf = 1240/671 = 1885 eV
not enough to eject any electron.
```

19. Consider a singly ionized He atom. What is the wavelength of a photon that is emitted as the atom makes a transition between the n = 5 and n = 3 states?

```
Z = 2.
```

1/lambda = 1.097x10^{7}Z^2(1/nf^2 - 1/ni^2)

a. 151 nm
b. 321 nm
c. 570 nm
d. 821 nm
e. 1282 nm

```
1/lambda = 10.97x10^7 x 2^2 x(1/9 - 1/25)
                      = 0.312 x 10^7
                      lambda = 3.2x 10^{-7}
```

20. What is the maximum number of electrons that can be found in the n = 3 shell of an atom?

2n^2 is the max

a. 14
b. 18
c. 24

```
n = 2
l =0 s 1
l= 1 p 3
l=2 d  5
so 9 orbits.
In each we have up and down spin electrons.
```

The next two questions pertain to the following situation:

Imagine a universe where the electron has a spin of 3/2. Its spin quantum number m_S could then have the following four values: m_S = +3/2, +1/2, –1/2, and –3/2.

21. If this were true, the first element with a filled shell would be the first of the noble gases and it would be:

A stupid question
contains 4 electrons, but is it called Be?

a. He with 2 electrons
b. Li with 3 electrons
c. Be with 4 electrons
d. C with 6 electrons
e. O with 8 electrons

22. Consider a beam of hydrogen atoms in the ground state (n = 1) in this universe where the electron has spin 3/2. The atoms are placed in a uniform B field. How many possible energy levels can the atoms be in?

ms levels are split.

a. 1
b. 2
c. 4
d. 6
e. 8

23. Of the hypothetical nuclear reactions below, which is possible? β^+ and β^- represent the positron (the antiparticle of the electron) and electron, with charges +1e, and –1e, respectively and ν and $\bar{\nu}$ represent (neutral) neutrinos.

Charge Z and the baryon number A must be conserved.

a. none are possible

b. ${}^{16}_{8}O + n \rightarrow {}^{17}_{8}O + \beta^- + \bar{\nu}$ Z not conserved

c. ${}^{14}_{7}N + {}^{1}_{1}H \rightarrow {}^{14}_{6}C + \beta^+ + \nu$ neither A nor Z conserved

d. ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow \alpha + n$

e. ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + \gamma$ Z not conserved

24. The nucleus of nitrogen ${}^{14}_{7}N$ has a mass of 13,040 MeV/c^2. What is the binding energy of this nucleus? (The mass of the proton is 938.3 MeV/c^2, and that of the neutron is 939.5 MeV/c^2)

mass deficit c^2 = binding energy

a. 2.2 MeV
b. 15.4 MeV
c. 47.9 MeV
d. 80.7 MeV
e. 104.6 MeV

14N consists of 7p and 7n = 13114.6 = 104.6 + 13040 MeV

25. A radioactive isotope has a half-life of 8 months. What fraction of a sample of the isotope will still remain after 2 years?

a. 1/32
b. 1/16
c. 1/8
d. 1/4
e. 1/2

half life -> N0 goes to N0/2
2 year = 24 = 3 half lives -> N0/8

The next two questions refer to the following situation:

The H-α line is a spectral line observed from the transition between n = 3 and n = 2 energy levels in hydrogen. It is often seen in the spectrum of light from celestial objects.

26. Determine the wavelength of light emitted from this transition for a source at rest.

a. 656 nm
b. 1240 nm
c. 374 nm

very similar to 19 but Z = 1

1/lambda = 1.097x10^{7}Z^2(1/nf^2 - 1/ni^2)

```
1/lambda = 1.097x10^7(1/4-1/9) = 0.152x10^{7}
lambda = 6.56 x 10^{-7}
```

27. The absorption spectrum of a distant galaxy exhibits an H-α line that is red-shifted by 1%. Given Hubble's law $v = H_0 d$ with H_0 = 70 km/s/Mpc, determine the distance to the galaxy in Megaparsecs (Mpc).

a. 90 Mpc
b. 43 Mpc
c. 17 Mpc

c = lambda f

v = H0d
v is the recessional speed

```
1% red shift (from the Doppler formula
fo = fe (1+v/c)) means v = 0.01 c
= 3x10^6 m/s

H0 = 70x10^3
d = v/H0 = 3x10^6/7x10^4 = 42.9 Mpc.
```

ANSWER KEY

1. A
2. A
3. B
4. E
5. B
6. C
7. A
8. E
9. C
10. C
11. C
12. E
13. A
14. A
15. B
16. C
17. A
18. A
19. B
20. B
21. C
22. C
23. D
24. E
25. C
26. A
27. B