Optics - Division B

Holt Invitational

2018 Science Olympiad

02/24/2018

School Name: _____

Team Name: _____ Team Number: _____

Team Members: _____

Test Instructions -

- Carefully read the rules below
- Clearly write your school name and team information.
- Do not turn this page until told to do so.
- Follow instructions to Start and Stop the exam.
- Go to the laser shoot station quietly, when asked to do so and return back to continue the exam.
- No electronic devices except calculators are allowed.
- All work must be legible and you must show your work to receive maximum points. Only partial points will be awarded for correct answers if the calculation steps are missing.
- Answer must be in metric unit. Answers without units will be considered incorrect.

60 points total + 3 tie-breaker

- 15 points – **Section1**: Electromagnetic waves/spectrum, Doppler effect, Polarization
- 15 points – **Section2:** Reflection, Mirrors, Diffraction, Color addition/subtraction
- 15 points – **Section3:** Refractions, Lens, Prisms
- 15 points – **Section4:** Eye, Working principles of common optical devices

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Intentionally left blank for rough work.

Section 1: 15 points

Fill-in the blanks (1 point for each blank):

1. The electromagnetic waves are a _____transverse_____ wave with orthogonally oscillating _____ electric_____ and _____magnetic_____ fields.

2. In the electromagnetic spectrum photons of the _____gamma- ray_____ wave have highest energy.

3. Compared to X-rays, the speed of light waves is _____same_____.

4. A black-light (or often black light bulb), is a lamp that emits mostly long-wave _____ultra-violet_____ light.

5. Cell-phone communication happens with _____radio/micro_____ waves.

6. Bluetooth headphones communicate with music players using _____radio _____ waves.

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7. One bright line in emission spectra has a wavelength of 600 nm. Calculate the energy of the photon of this light. Consider: Speed of light is $3X10^{8}$ m/s and Planck's constant as $6.626X10^{-34}$ J-s **(2 Points)**

   Frequency (μ) = c/λ = ($3X10^{8}$ m/s) / (600 nm) = $5\ X10^{14}$ Hz

   Energy of photon = h * μ = $6.626X10^{-34}$ J-s X $5\ X10^{14}$ Hz =$33.13\ X10^{-20}$ Joules

Solve the problems. Show your work and circle final answer.

8. A star is moving at a velocity of 500 km/s away from us. If it emits light at a wavelength of 500 nm, what is the difference between that and the wavelength we observe? **(3 points.)**

Assume, observed wavelength = λ_o

λ_e = emitted wavelength = 500 nm

V_s = velocity of emitting source = 500 km/s = 5 X 10^5 m/s

Using Doppler equation,

$\lambda_o = (1 - V_s/c)\,\lambda_e = (1 - (5 \times 10^5 \text{ m/s})/(3 \times 10^8 \text{ m/s})) \times 500 \text{ nm} = (1 - (1/600)) \times 500 \text{ nm}$

$\lambda_e - \lambda_o = 500 \text{ nm} - (1 - (1/600)) \times 500 \text{ nm} = 500/600 \text{ nm} = 0.833 \text{ nm}$

Difference between that and the wavelength we observe =0.833 nm

9. If the refractive index of air is taken to be unity and that of water to be 1.330, at what angle of reflection (in degrees) will light in air be completely polarized by water? What do you call this angle? **(2 points)**

Θ= Angle of reflection = Angle of incidence

$\tan(\Theta) = 1.33$

$\Theta = \tan^{-1}(1.33) = 53.06^o$

This angle is called Brewster Angle.

Section 2: 15 points

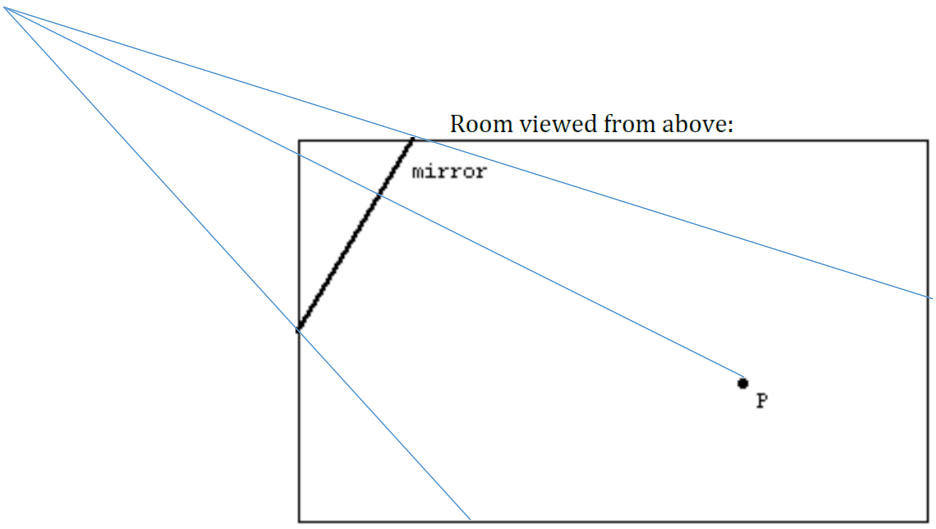
Fill-in the blanks (1 point for each blank):

10. _____Shading_____ is the term used for adding black to a color?

11. Color inkjet printers use CMYK pigments. Letter K stands for _____black_____ color.

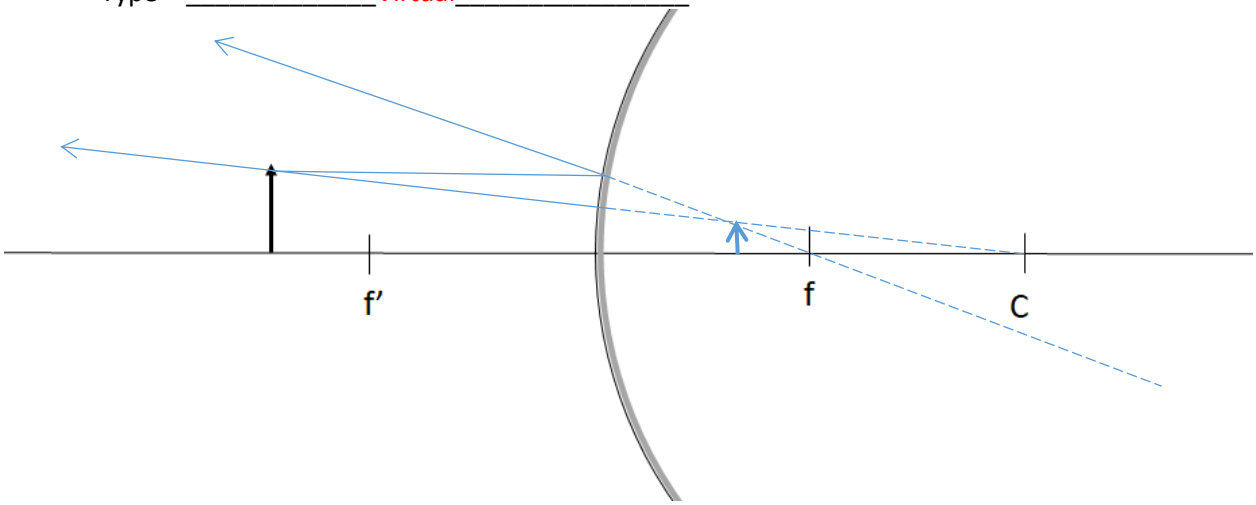
12. When red and green light shine on a sheet of white paper, the resulting color is _____yellow_____.

13. Draw in rays of light to show how much of the room a person can see from point P by looking only in the mirror. Shade in what portions of the room the person at point P cannot see when looking only in the mirror. **(2 points)**



14. Draw the images of the Arrow line in the following curved mirror **(2 points)**. Specify the location, orientation, type of the image **(3 points)**.

Location = _____Behind the mirror_____
Orientation = _____Upright_____
Type = _____Virtual_____



15. If the radius of curvature of the above mirror is 60 cm and the height of the object is 20 cm and is located 40 cm from the mirror. What is the height of the image? **(2 points)**

$1/(-30) = 1/40 + 1/D_i \Rightarrow 1/D_i = -1/30 - 1/40 \Rightarrow D_i = -120/7$ cm

$H_i/20 = -\ ((-120/7) /40) \Rightarrow H_i = 60/7$ cm $= 8.57$ cm

16. A laser passes through a double-slit [slits are separated by a distance of 0.06 mm] and projects onto a whiteboard located 3 meters away. The distance measured between the central bright band and the second bright band is 6 cm. What would be the measured wavelength of light? **(3 points)**

Using Young's equation to calculate the wavelength

$\lambda = y \bullet d / (m \bullet L)$

$\lambda = [(6 \text{ cm}) \bullet (0.06 \text{ mm})] / [(2) \bullet (3 \text{ m})]$

$\lambda = [(6 \times 10^{-2} \text{ m}) \bullet (6 \times 10^{-5} \text{ m}) / [(2) \bullet (3 \text{ m})] = 6 \times 10^{-7} \text{ m}$

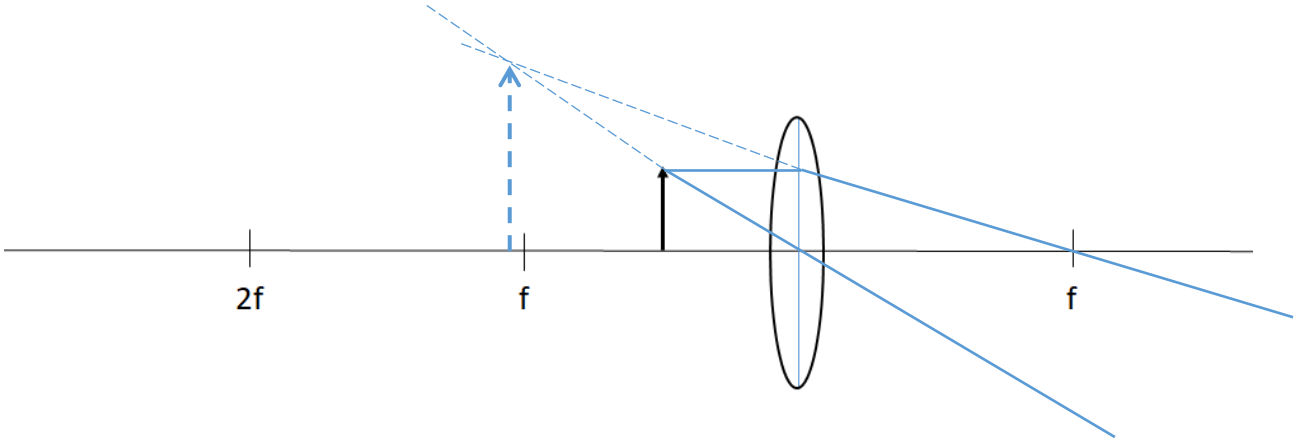
Finally convert to nanometers

$\lambda = 6 \times 10^{-7} \text{ m} = 600 \text{ nm}$

Section 3: 15 points

17. Draw the ray diagram for the object located in front of a converging lens? **(2 points)**. Specify the location, orientation, type of the image **(3 points)**.

Location = _____Behind the object_____
Orientation = _____Upright_____
Type = _____Virtual_____



18. If the focal length of the above lens is 50 cm and the height of the object is 20 cm and is located 20 cm from the lens. What is the height of the image? **(2 points)**

$1/50 = 1/20 + 1/D_i \Rightarrow 1/D_i = 1/50 - 1/20 \Rightarrow D_i = -33.33$ cm

$H_i/20 = -\ ((-33.33)/20) \Rightarrow H_i = -33.33$ cm

19. What is their angle of minimum deviation for a prism with an apex angle of 60° and refractive index of 1.31.? **(3 points)**

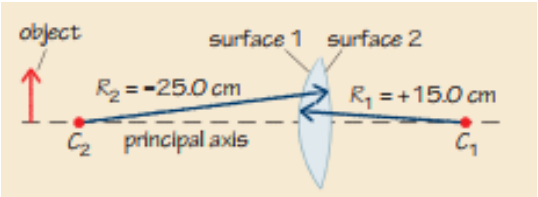
Prism of apex angle (σ) = 60°
Prism index of refraction (n_{prism}) = 1.31 and Air refractive index (n_0) = 1.00
Assume angle of minimum deviation = δ

Using the following formula

$$\frac{n_{prism}}{n_0} = \frac{\sin\frac{1}{2}(\sigma+\delta)}{\sin\frac{1}{2}\sigma}$$

$\delta = 21.84°$

20. In the figure shown the front surface (surface 1) of the lens has a radius of curvature of magnitude 15.0 cm, and the back surface(surface 2) has a radius of curvature of magnitude 25.0 cm. The lens is made of crown glass with an index of refraction1.520. Calculate the focal length of the lens. What is the power of the lens? **(2 points)**



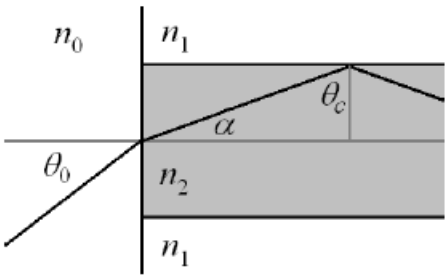
Using lens maker's equation for thin lens

$$\frac{1}{f} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right].$$

1/f = (1.52-1) [(1/15) – (– 1/25)] = 0.0555 cm^{-1}
f = 18 cm.

Power of lens = 1/focal length in meters = 100/18 = 5.55 m^{-1} or 5.55 Diopters

21. A fiber optic cable with refractive index (n_2 =1.44) is submerged in the water (n_1 =1..33). A ray of light is incident on the fiber optic cable from air (n_0 =1) at an angle Θ_0. (See the picture below). What is the maximum angle of incidence (Θ_0) for which the light will not escape the fiber optic cable? **(3 points)**



$n_2 \sin \Theta_c = n_1 \sin 90^o$
$\Theta_c = \arcsin(n_1/n_2) = \arcsin(1.33/1.44) = 67.46^o$

$\alpha = 90^o - \Theta_c = 22.54^o$

$n_0 \sin \Theta_0 = n_1 \sin \alpha = 1.33 \times \sin(22.54^o) = 0.51$
$\Theta_0 = \arcsin(0.51) = 30.66^o$

Minimum angle of incidence = 30.66^o

Section 4: 15 points

Fill-in the blanks (1 point for each blank):

22. The ____Retina_____ is made up of 2 types of photoreceptors, the _____rods_____(responsive in low light) and the _____cones_____ (responsive to color).

23. Human is eye is most sensitive to color _____green-blue_____.

24. _____Ciliary_____ muscles changes the shape of the lens within the eye.

25. _____Cornea_____ is the transparent tissue covering the front of the eye: does not have blood vessels; does have nerves.

26. _____Iris_____ is the circular band of muscles that controls the size of the pupil.

27. _____Macula_____ is small central area of the retina that provides vision for fine work and reading.

28. _____Optic nerve_____ is composed of retinal ganglion cell axons and glial cells.

29. _____Lens_____ of the eye changes its shape when needed to focus image on retina.

30. What is the magnification(M) and field of view (FOV)of a telescope with the following specifications **(2 points)** –

- Objective lens diameter (D_O)= 152mm
- Objective lens focal length (f_O)= 762mm
- Eyepiece lens focal length (f_e)= 25mm
- Eyepiece field of view (FOV_e)= 52°

Magnification (M) = f_O / f_e = 762/25 = 30.48

Field of view (FOV)of the telescope (FOV_{scope}) = FOV_e / M = 52/30.48 = 1.7^o

31. The diameter of the James Webb Space Telescope is 6.5 meters. If it is observing objects at a wavelength of 15 microns, what is its diffraction limit (resolution) in milliarcseconds? **(3 points)**

Angular resolution (Θ) for wavelength (λ) and lens aperture (D) is

$$\theta = 1.220\frac{\lambda}{D}$$

Θ = 1.22 X (15 μm / 6.5 m) = 2.81 X 10^{-6} radians
= 2.81 X 10^{-6} X (180/π) degrees = 161.31 x 10^{-6} degrees
= 161.31 x 10^{-6} X 60 X 60 X 1000 milliarcseconds = 580.7 mas

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Tie Breaker:

32. The intensity of radiation from the Sun is ~1370 W/m^2 on Earth (1 AU from the sun). What is the Sun's intensity at Mercury (0.387 AU)? **(2 points)**

1370/$(.387)^2$ = 9140 W/m^2

33. A thin converging lens with a focal length of 30 cm produces a virtual image 30 cm away. What is the object distance? **(1 point)**

15 cm