Question 2

12 points total — **Distribution of points**

(a) 3 points

For graphing angles or functions of angles on the axes	1 point
For plotting sines of angles on the axes and indicating or implying that the index of refraction of air is 1	1 point
For indicating a method to determine the index of refraction of the glass that is consistent with the graph described	1 point

Example: If 1 refers to air and 2 to the glass, use $n_1 \sin\theta_1 = n_2 \sin\theta_2$ and graph $\sin\theta_1$ as a function of $\sin\theta_2$. Because $n_1 = 1$, the slope of the line is n_2.

(b) 4 points

For indicating that the light from the lamp needs to be a beam when it enters the glass (either referring to a beam, explicitly describing how to create a beam, or showing a beam in a diagram)	1 point
For describing some method of determining angles with a protractor (or equivalent tool) in both media at an appropriate boundary	1 point
For using angles with respect to the normal (can measure any angles as long as reference is made to converting them to the correct ones)	1 point
For repeating the measurement at three or more different incidence angles to obtain sufficient data	1 point

(c) 2 points

For indicating that when light travels across the boundary from air to glass, the ray bends toward the normal	1 point
For indicating that the speed of light is slower in glass than in air (or an answer consistent with response for bending of the ray)	1 point

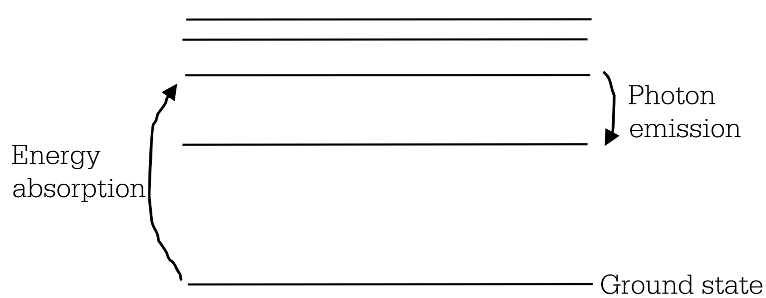
Question 2 (continued)

Distribution of points

(d) 3 points

For an appropriate energy-level diagram showing absorption from the lowest level and emission	1 point
For indicating that a hydrogen atom can be excited from the ground state to a higher energy state by absorbing energy	1 point
For indicating that transitions to lower energy levels cause emission of photons	1 point

Example:



Atoms in the ground state absorb energy from the electricity delivered to the lamp. The atoms enter an excited state. Then the atoms emit photons as they drop to a lower energy state.

2. (12 points, suggested time 25 minutes)

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

(a) A linear graph is to be used to determine the index of refraction of the glass. Indicate the quantities that should be graphed and describe how the graph could be used to determine the index of refraction of the glass.

$n_1 \sin\theta_1 = n_2 \sin\theta_2$ — n_1 drops out as it is equal to 1 in air.

$\sin\theta_1 = n_2 \sin\theta_2$ — n_2 should be solved for as it is the unknown.

$n_2 = \frac{\sin\theta_1}{\sin\theta_2}$ — Thus $\sin\theta_1$ should be graphed on the y-axis and $\sin\theta_2$ should be graphed on the x-axis, so that n_2 is equal to $\frac{y}{x}$ or the slope of the graph.

(b) Outline an experimental procedure that could gather the necessary data. Include sufficient detail so that another student could follow your procedure. In addition to the glass block and the hydrogen lamp, the equipment in a typical classroom laboratory is available.

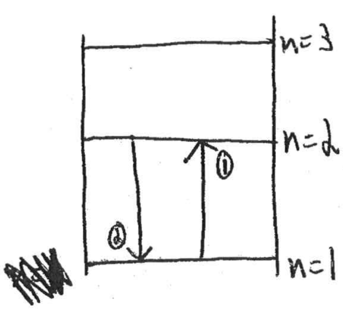
The lamp should be set up using a slit so that only a thin beam of light is emitted. The glass block should be in line with this beam and placed on a turnable surface independent of the rest of the apparatus. Measurements can then be made by using a protractor to measure the angle the beam of light makes with the glass block just before entering, and the angle the beam of light makes with the glass block just after entering. All angles should be measured from the normal line. The first angle measured, or the "incident angle," should be changed so that multiple measurements can be taken.

(c) Predict how the path of the light will change as it enters the glass. Support your prediction using a qualitative comparison of the speed of light in glass and the speed of light in air.

The path of the light will bend toward the normal line so that the angle of refraction is less than the angle of incidence. Looking at $n_1 \sin\theta_1 = n_2 \sin\theta_2$ we can see that when the index of refraction, n_2, is greater than n_1 then $\sin\theta_2$ must be less than $\sin\theta_1$. Thus $\theta_2 < \theta_1$. The speed of light as it travels through glass is less than the speed of light as it travels through air. Therefore, since $n = \frac{c}{v}$, when v is less n must increase. Thus n_{glass} is greater than n_{air}.

(d) Describe the process(es) by which red light from the lamp is produced by hydrogen atoms that are initially in the ground state. Draw and label an energy level diagram that supports the atomic process(es) you describe.

Hydrogen atoms in the ground state are excited by other photons. The atoms move to higher energy states as a result of being excited, and gaining energy from the photons. The atoms then drop to lower energy states or the ground state and release some or all of the energy they absorbed, respectively.



In step 1 energy is absorbed by the atom and it is excited to a higher energy level. In step 2 the energy is released in the form of a photon. The atom could have also been excited t n=3 and then dropped to either n=2 or n=1. If it dropped to n=2 and then t n=1 the atom would release a photon tw times - once for each energy level change

GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

(a) A linear graph is to be used to determine the index of refraction of the glass. Indicate the quantities that should be graphed and describe how the graph could be used to determine the index of refraction of the glass.

The graph should be a graph of the $\sin\theta_1$ (the sin of the angle that the light ray entering the glass deviates from the normal line) vs. $\sin\theta_2$ (the sin of the angle that the light ray leaving the glass deviates from the normal line). By using the slope of this graph and the index of refraction of air, we can find the index of refraction of the glass. we would simply do

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

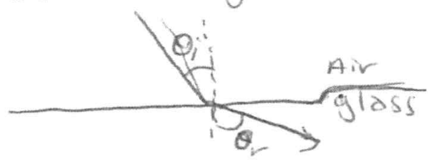
(b) Outline an experimental procedure that could gather the necessary data. Include sufficient detail so that another student could follow your procedure. In addition to the glass block and the hydrogen lamp, the equipment in a typical classroom laboratory is available.

Before we begin the experiment, we will need the glass block, the hydrogen lamp, a protractor, a calculator, and something to graph the graph on. We will begin by shining the hydrogen lamp at the glass block at a 90° angle to the surface of the glass block. The angle θ_1 would be 90, so $\sin\theta_1$ would be 1. θ_2 would be the angle between the normal line (the line perpendicular to the surface of the glass block) and the light ray leaving the block. After this, you start decreasing the angle between the light ray and the surface of the glass block, calculating $\sin\theta_1$ and $\sin\theta_2$ for each angle and recording the data on the graph. Remember, θ_1 would be the angle between the incident ray and the normal line and θ_2 would be the angle between the refracted ray and the normal line.

GO ON TO THE NEXT PAGE.

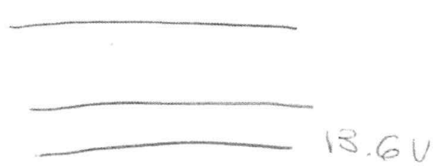
(c) Predict how the path of the light will change as it enters the glass. Support your prediction using a qualitative comparison of the speed of light in glass and the speed of light in air.

The path of the light would change in a way that would make the refract-ed light ray be farther from the normal line than the incident light ray was. Glass is much more dense than air is, so when the light goes into the glass, it travels much slower than it would travel in air. Because of this, the angle between the refracted ray and the normal line increase.



(d) Describe the process(es) by which red light from the lamp is produced by hydrogen atoms that are initially in the ground state. Draw and label an energy level diagram that supports the atomic process(es) you describe.

Hydrogen atoms in the lamp are taken from the ground state and given energy, making them excited atoms. When these atoms are excited, they can release photons, which would be thermodynamically favorable, and would allow them to return to their natural, unexcited state. The light is red because it doesn't have energy because the Hydrogen atoms weren't excited enough to give off photons with greater energy.



GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

(a) A linear graph is to be used to determine the index of refraction of the glass. Indicate the quantities that should be graphed and describe how the graph could be used to determine the index of refraction of the glass. The quantities that should be graphed are the angle of incedence & angle of refraction. The slope that is made by the graph would equal the index of refraction

(b) Outline an experimental procedure that could gather the necessary data. Include sufficient detail so that another student could follow your procedure. In addition to the glass block and the hydrogen lamp, the equipment in a typical classroom laboratory is available.

Step 1.) create a unit circle arond the glass block with the glass block in the center. Lable incraments of 15° around the unit circle.

Step 2.) place hydrogen lamp facing the block and at an angle of incedence ≥ 15°.

Step 3.) Record the angle the light refracts from the glass block

Step 4.) Move the hydrogen lamp to a new angle and then repeat step 3

Step 5.) Repeat step 4 untill all the needed data has been recorded

step 6.) Graph data & draw a best fit line

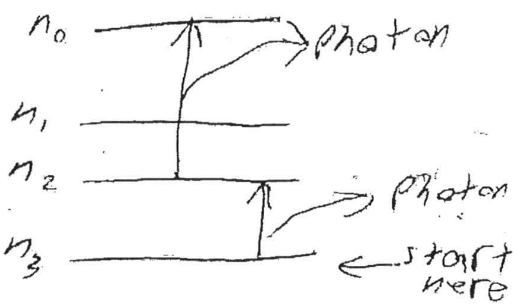
GO ON TO THE NEXT PAGE.

(c) Predict how the path of the light will change as it enters the glass. Support your prediction using a qualitative comparison of the speed of light in glass and the speed of light in air.

The light will slow down as it enters the glass. when the light goes from the air to the glass, the wavelength decreases but the frequency stays the same. This will cause the light to travel slightly slower in the glass than in the air.

(d) Describe the process(es) by which red light from the lamp is produced by hydrogen atoms that are initially in the ground state. Draw and label an energy level diagram that supports the atomic process(es) you describe.

The hydrogen atoms are not at a ground state. Each atom has energy it can shed which comes in the form of photons. when an atom drops energy levels it will emit a photon of light to release some energy for it to drop down.



GO ON TO THE NEXT PAGE.

AP® PHYSICS 2
2016 SCORING COMMENTARY

Question 2

Overview

This question assessed learning objectives 1.A.4.1, 6.E.3.2, 6.E.3.3, and 7.C.4.1. The question evaluated student understanding of Snell's law and energy level diagrams. The basic intent was to assess students' experimental design skills. These include experimental procedure design, a description of what data needs to be analyzed, and how to perform that analysis.

Sample: P2 Q2 A
Score: 12

Part (a) earned 3 points. The response clearly identifies Snell's law and then indicates that $n_{air} = 1$ and n_2 is the unknown index of the glass. It indicates appropriate quantities to graph on each axis and the appropriate method of using the slope of the graph. Part (b) earned 4 points. The response describes the formation of a beam, measurement of the beam angle relative to the normal and at appropriate locations (just before and just after the beam enters the glass) using a protractor, and changing the incident angle to obtain multiple measurements. Part (c) indicates that the light bends toward the normal upon entering the glass, with an explanation that includes the fact that the speed of light is slower in glass, and earned 2 points. Finally, part (d) contains a neat and accurate energy level diagram and an explanation of both the absorption/excitation process and the emission/de-excitation process, which earned 3 points.

Sample: P2 Q2 B
Score: 9

Part (a) earned 3 points. The response uses Snell's law and indicates that the sines of the angles should be graphed. It implies that n_{air} is known and appropriately uses the slope of the graph to determine the index of the glass. Part (b) refers to a light ray, mentions a protractor, measures angles with respect to the normal, and measures decreasing incident angles implying three or more measurements. However, in both (a) and (b) the description of θ_2 is the angle of the light ray leaving the block, which is incorrect, so part (b) earned 3 points. Part (c) correctly indicates that the speed of light is slower in glass, but incorrectly shows the bending due to refraction, so only 1 point was earned. Part (d) earned 2 points for the description of absorption and emission, but the diagram does not show transitions.

Sample: P2 Q2 C
Score: 4

Part (a) indicates graphing angles, not their sines. The slope of such a graph would not be relevant to finding the unknown index of refraction. Only 1 point was earned. In part (b) there is no mention of a beam or of measuring angles with respect to the normal. The unit circle labeled in increments of 15 degrees can be used to measure angles, and the measurements are taken for at least three incident angles, so 2 points were earned. Part (c) has no prediction to support, and earned no credit. The diagram in part (d) may be intended to illustrate emission, given that the labels have increasing numbers going down, but it definitely does not show both absorption and emission. The response does describe emission in words, which earned 1 point.