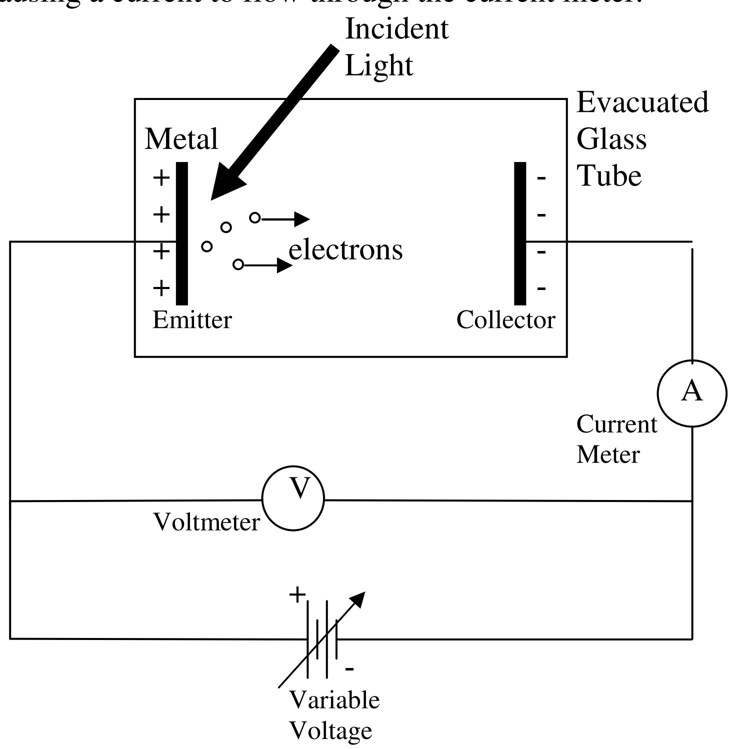
Physics 220 Lab - Spring 2009
Lab 5: The Photoelectric Effect

Introduction

The experimental set-up for the photoelectric effect is shown in the diagram below. Light falls on a metal surface inside an evacuated glass tube. The light strikes the surface of the metal, transferring their energy to some of the electrons in the metal. The kinetic energy gained by the electrons may allow some to escape from the surface. Some of these ejected electrons will travel across the tube to the collector, causing a current to flow through the current meter.



In the classical analysis of this interaction, the energy of the electrons knocked loose from the metal surface is expected to increase if the intensity (amplitude) of the light wave is increased. Thus brighter light (of any color or frequency) should produce electrons with more kinetic energy, and dimmer light should produce electrons with less kinetic energy.

In quantum theory, the energy of the incident photons depends only on the *frequency* of the light, through the relation

$$E_{photon} = hf \qquad (1)$$

where h is Planck's constant and f is the frequency of the light. Allowing for the loss of kinetic energy as the electrons escape from the surface, Einstein predicted the maximum kinetic energy of the ejected electrons to be

$$KE_{max} = hf - \phi \qquad (2)$$

where ϕ is the work function of the metal from which the electrons are ejected.

To determine the kinetic energy of the ejected electrons, a voltage source is used to induce a positive charge on the emitter and a negative charge on the collector. The electric field produced by these charges opposes the flow of electrons between the emitter and the collector. When the voltage is high enough, the electrons return to the metal plate (the emitter) rather than traveling to the collector.

The voltage at which the electric current between the emitter and the collector is stopped is called the "stopping potential." The stopping potential (ΔV_s) is related to the maximum kinetic energy of the electrons through the relation

$$KE_{max} = e\Delta V_s \qquad (3)$$

where e is the charge on the electron.

Combining Equations (2) and (3), we have

$$e\Delta V_s = hf - \phi \qquad (4)$$

or

$$\Delta V_s = (h/e)f - \phi/e \qquad (5)$$

Pre-lab questions:

1. What are the slope and y-intercept of a plot with stopping potential on the vertical axis and frequency on the horizontal axis?

2. In order to help you visualize what's going on in the photoelectric effect experiment, take a look at a simulation.

Go to http://phet.colorado.edu/simulations/ and click on Quantum Phenomena, and then open the Photoelectric Effect simulation. Run this simulation.

Check the box to Show only highest energy electrons. Make sure the target is sodium.
Set the wavelength to about 500 nm
Set the battery voltage to 0.00 V
Set the intensity to about 50%
and observe what happens to the current and to the speed (kinetic energy) of the electrons.

Investigate the effects of changing the intensity while keeping the wavelength constant.

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Set the wavelength to a value at which there's a current flowing. Wavelength chosen: _______
Try to stop the current by changing the battery voltage. Battery voltage at which the current goes to zero: ________.

Repeat for a shorter wavelength to see how the battery voltage needed to stop the current depends on the wavelength of the incident light.

Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
- How does the maximum kinetic energy of the emitted electrons depend on the intensity of the light?
- What is the role of the voltage provided by the battery in this experiment? (What does this voltage allow you to measure?)

Experimental Overview and Detailed Procedures

This lab consists of two experiments, the first to investigate the relationship between the intensity of the light source and the kinetic energy of the ejected electrons, and the second to determine the dependence of the electron energy on the frequency of the incident light. The second experiment will also allow you to determine Planck's constant and the work function of the metal used in the photodiode.

The light source used in this experiment is a mercury-vapor tube. Like all excited gases, the mercury vapor in this tube does not produce a continuous spectrum of light, but instead produces narrow spectral lines only at certain wavelengths. For this experiment, we will use five different spectral lines of mercury. The wavelength values are given in the manual for the apparatus. Note: the white mask on the h/e apparatus is made of a fluorescent material to enable you to see the ultraviolet line.

To separate the light in each of these lines, the light from the mercury vapor is passed through a diffraction grating. The line pattern in this grating causes light of different wavelengths to interfere constructively at different angles. The relationship between the wavelength of the light and the angle of constructive interference is given by

$$d \sin\theta = m\lambda \qquad (m = 1, 2, 3, \ldots)$$

where d is the spacing between the enscribed lines on the grating and m is the order number of the maxima. Two filters (a yellow and a green) are included in order to prevent room light from affecting the results when the yellow and green lines are used.

You also have a variable transmission filter that will let you vary the intensity of the light without changing the wavelength.

The h/e apparatus will measure the stopping potential by allowing electrons ejected from the emitter to charge up a small capacitor. When the voltage on this capacitor equals the stopping potential, the current through the photodiode falls to zero and the voltage output of the h/e apparatus reaches a stable value. This value, read by a digital voltmeter, is approximately the stopping potential. The reason this is only *approximately* the stopping potential is that, as the ejected electrons build up charge on the capacitor, some of the previously stored charge may leak away. Thus, depending on the experimental parameters, there may be a small difference between the output voltage of the h/e apparatus and the true stopping potential.

Examine the various pieces of the apparatus. On the h/e apparatus containing the photodiode, gently roll the cylindrical light shield away from the aperture so that you can see inside. Darken the room so that you can easily see the spectral lines produced by the light source and diffraction grating. Now rotate the h/e apparatus about the pin in the coupling arm so that the light from one of the spectral lines falls on the aperture. You may notice a difference in brightness between the lines on one side and on the other side (this is due to the diffraction grating's construction)—if so, choose the brighter side. If necessary, rotate the apparatus so that the light entering through the aperture falls on the two small squares on the white photodiode mask.

Make sure that only one of the spectral lines falls on the opening of the photodiode mask. Move the diffraction grating to focus the line on the mask. If you select the green or yellow spectral line, place the corresponding colored filter over the aperture of the h/e apparatus to block any other wavelengths of light.

Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

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Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

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Use your measurements along with Equation (5) to determine the values of Planck's constant (h) and the work function (ϕ) for the metal in the photodiode used in the h/e apparatus. Make an appropriate plot of the data and fit it with a straight line, and use the slope and intercept (with their uncertainties) to find values for $h \pm \Delta h$ and for $\varphi \pm \Delta\varphi$.

In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?

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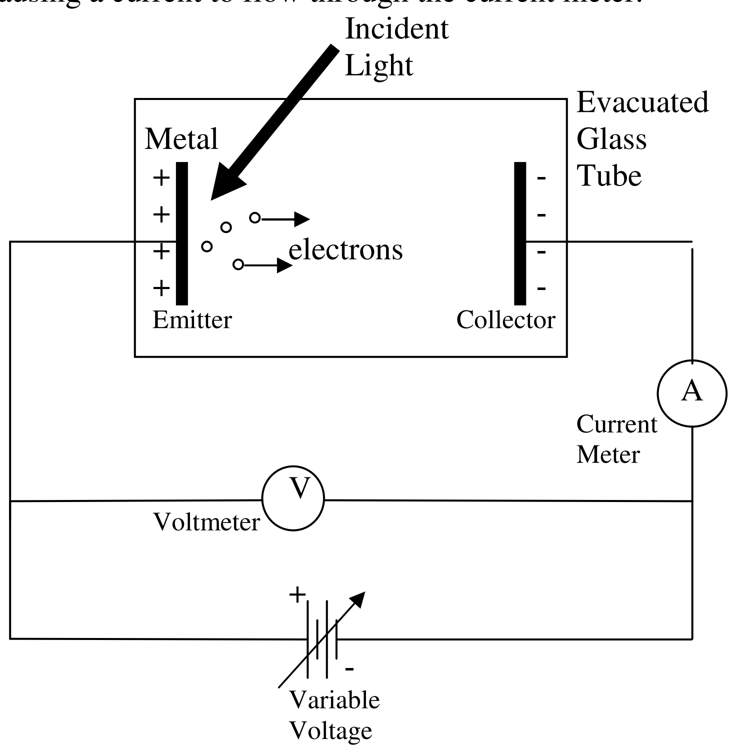

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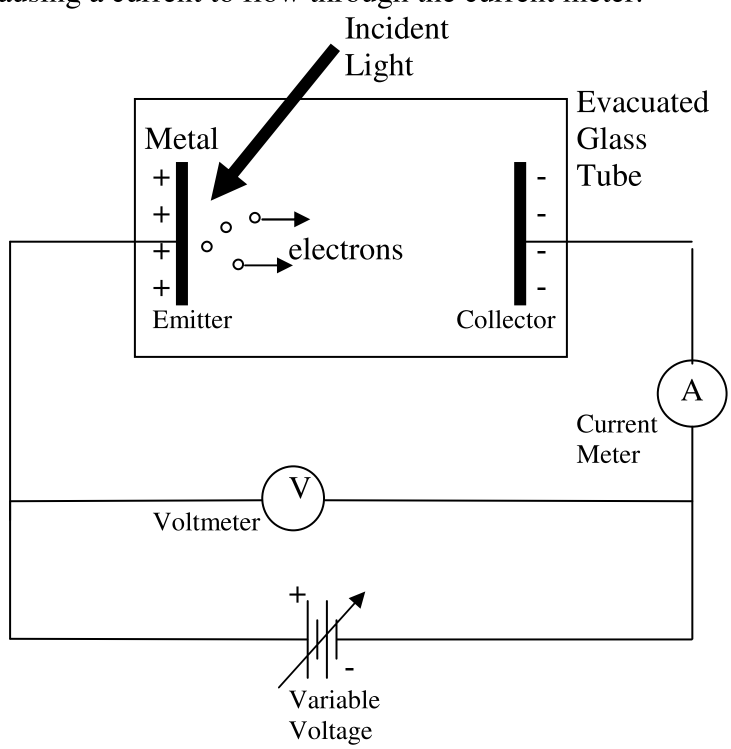

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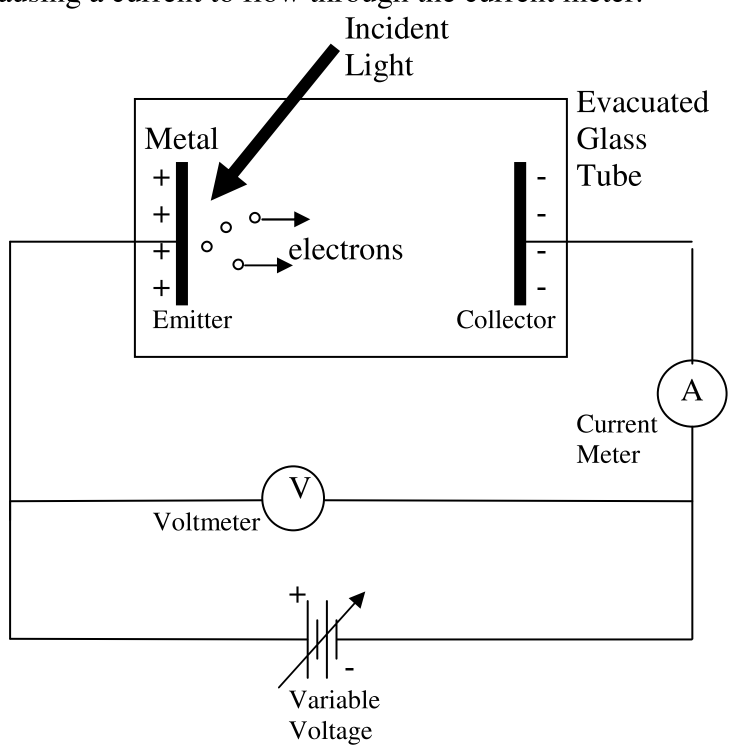

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Make sure that only one of the spectral lines falls on the opening of the photodiode mask. Move the diffraction grating to focus the line on the mask. If you select the green or yellow spectral line, place the corresponding colored filter over the aperture of the h/e apparatus to block any other wavelengths of light.

Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

Experiment #1: Relationship of Light Intensity and Ejected Electron Energy
Design an experiment to investigate whether the maximum kinetic energy of the ejected electrons depends on the intensity of the light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results.

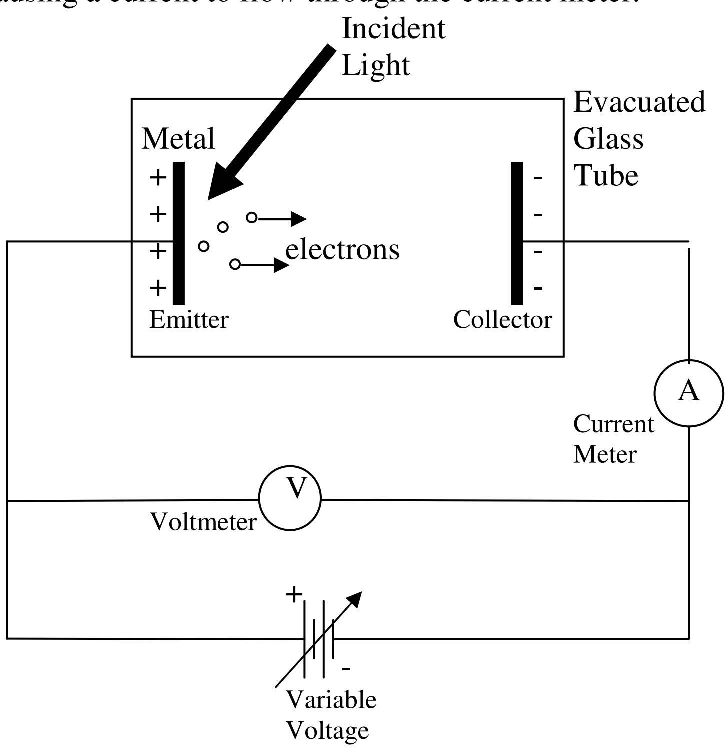
Use your measurements along with Equation (5) to determine the values of Planck's constant (h) and the work function (ϕ) for the metal in the photodiode used in the h/e apparatus. Make an appropriate plot of the data and fit it with a straight line, and use the slope and intercept (with their uncertainties) to find values for $h \pm \Delta h$ and for $\varphi \pm \Delta\varphi$.

In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?

Physics 220 Lab - Spring 2009
Lab 5: The Photoelectric Effect

Introduction

The experimental set-up for the photoelectric effect is shown in the diagram below. Light falls on a metal surface inside an evacuated glass tube. The light strikes the surface of the metal, transferring their energy to some of the electrons in the metal. The kinetic energy gained by the electrons may allow some to escape from the surface. Some of these ejected electrons will travel across the tube to the collector, causing a current to flow through the current meter.



In the classical analysis of this interaction, the energy of the electrons knocked loose from the metal surface is expected to increase if the intensity (amplitude) of the light wave is increased. Thus brighter light (of any color or frequency) should produce electrons with more kinetic energy, and dimmer light should produce electrons with less kinetic energy.

In quantum theory, the energy of the incident photons depends only on the *frequency* of the light, through the relation

$$E_{photon} = hf \qquad (1)$$

where h is Planck's constant and f is the frequency of the light. Allowing for the loss of kinetic energy as the electrons escape from the surface, Einstein predicted the maximum kinetic energy of the ejected electrons to be

$$KE_{max} = hf - \phi \qquad (2)$$

where ϕ is the work function of the metal from which the electrons are ejected.

To determine the kinetic energy of the ejected electrons, a voltage source is used to induce a positive charge on the emitter and a negative charge on the collector. The electric field produced by these charges opposes the flow of electrons between the emitter and the collector. When the voltage is high enough, the electrons return to the metal plate (the emitter) rather than traveling to the collector.

The voltage at which the electric current between the emitter and the collector is stopped is called the "stopping potential." The stopping potential (ΔV_s) is related to the maximum kinetic energy of the electrons through the relation

$$KE_{max} = e\Delta V_s \qquad (3)$$

where e is the charge on the electron.

Combining Equations (2) and (3), we have

$$e\Delta V_s = hf - \phi \qquad (4)$$

or

$$\Delta V_s = (h/e)f - \phi/e \qquad (5)$$

Pre-lab questions:

1. What are the slope and y-intercept of a plot with stopping potential on the vertical axis and frequency on the horizontal axis?

2. In order to help you visualize what's going on in the photoelectric effect experiment, take a look at a simulation.
Go to http://phet.colorado.edu/simulations/ and click on Quantum Phenomena, and then open the Photoelectric Effect simulation. Run this simulation.

Check the box to Show only highest energy electrons. Make sure the target is sodium.
Set the wavelength to about 500 nm
Set the battery voltage to 0.00 V
Set the intensity to about 50%
and observe what happens to the current and to the speed (kinetic energy) of the electrons.

Investigate the effects of changing the intensity while keeping the wavelength constant.

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Set the wavelength to a value at which there's a current flowing. Wavelength chosen: _______
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Repeat for a shorter wavelength to see how the battery voltage needed to stop the current depends on the wavelength of the incident light.

Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
- How does the maximum kinetic energy of the emitted electrons depend on the intensity of the light?
- What is the role of the voltage provided by the battery in this experiment? (What does this voltage allow you to measure?)

Experimental Overview and Detailed Procedures

This lab consists of two experiments, the first to investigate the relationship between the intensity of the light source and the kinetic energy of the ejected electrons, and the second to determine the dependence of the electron energy on the frequency of the incident light. The second experiment will also allow you to determine Planck's constant and the work function of the metal used in the photodiode.

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$$d \sin\theta = m\lambda \quad (m = 1, 2, 3, \ldots)$$

where d is the spacing between the enscribed lines on the grating and m is the order number of the maxima. Two filters (a yellow and a green) are included in order to prevent room light from affecting the results when the yellow and green lines are used.

You also have a variable transmission filter that will let you vary the intensity of the light without changing the wavelength.

The h/e apparatus will measure the stopping potential by allowing electrons ejected from the emitter to charge up a small capacitor. When the voltage on this capacitor equals the stopping potential, the current through the photodiode falls to zero and the voltage output of the h/e apparatus reaches a stable value. This value, read by a digital voltmeter, is approximately the stopping potential. The reason this is only *approximately* the stopping potential is that, as the ejected electrons build up charge on the capacitor, some of the previously stored charge may leak away. Thus, depending on the experimental parameters, there may be a small difference between the output voltage of the h/e apparatus and the true stopping potential.

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Make sure that only one of the spectral lines falls on the opening of the photodiode mask. Move the diffraction grating to focus the line on the mask. If you select the green or yellow spectral line, place the corresponding colored filter over the aperture of the h/e apparatus to block any other wavelengths of light.

Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

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Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results.

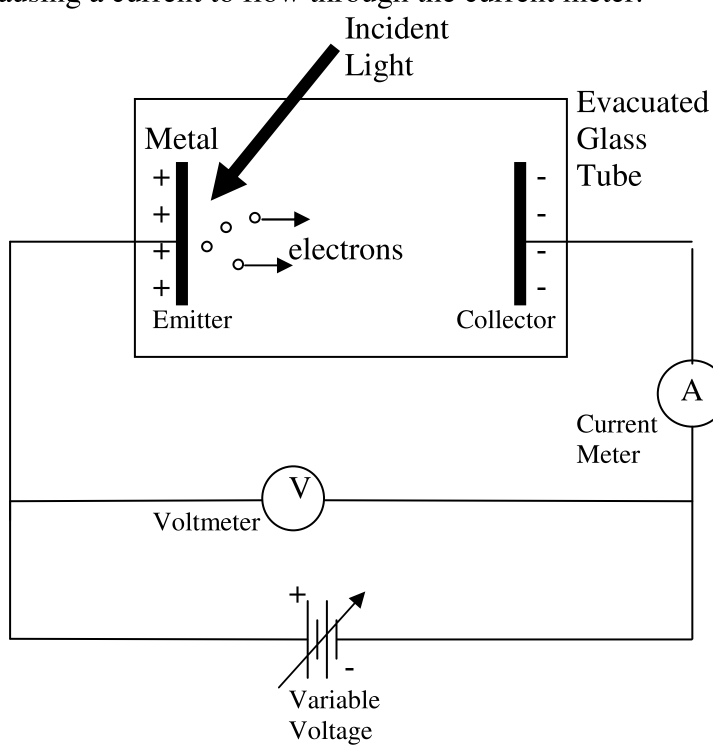
Use your measurements along with Equation (5) to determine the values of Planck's constant (h) and the work function (ϕ) for the metal in the photodiode used in the h/e apparatus. Make an appropriate plot of the data and fit it with a straight line, and use the slope and intercept (with their uncertainties) to find values for $h \pm \Delta h$ and for $\varphi \pm \Delta\varphi$.

In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?

Physics 220 Lab - Spring 2009
Lab 5: The Photoelectric Effect

Introduction

The experimental set-up for the photoelectric effect is shown in the diagram below. Light falls on a metal surface inside an evacuated glass tube. The light strikes the surface of the metal, transferring their energy to some of the electrons in the metal. The kinetic energy gained by the electrons may allow some to escape from the surface. Some of these ejected electrons will travel across the tube to the collector, causing a current to flow through the current meter.



In the classical analysis of this interaction, the energy of the electrons knocked loose from the metal surface is expected to increase if the intensity (amplitude) of the light wave is increased. Thus brighter light (of any color or frequency) should produce electrons with more kinetic energy, and dimmer light should produce electrons with less kinetic energy.

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The voltage at which the electric current between the emitter and the collector is stopped is called the "stopping potential." The stopping potential (ΔV_s) is related to the maximum kinetic energy of the electrons through the relation

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Pre-lab questions:

1. What are the slope and y-intercept of a plot with stopping potential on the vertical axis and frequency on the horizontal axis?

2. In order to help you visualize what's going on in the photoelectric effect experiment, take a look at a simulation.
Go to http://phet.colorado.edu/simulations/ and click on Quantum Phenomena, and then open the Photoelectric Effect simulation. Run this simulation.

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Repeat for a shorter wavelength to see how the battery voltage needed to stop the current depends on the wavelength of the incident light.

Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
- How does the maximum kinetic energy of the emitted electrons depend on the intensity of the light?
- What is the role of the voltage provided by the battery in this experiment? (What does this voltage allow you to measure?)

Experimental Overview and Detailed Procedures

This lab consists of two experiments, the first to investigate the relationship between the intensity of the light source and the kinetic energy of the ejected electrons, and the second to determine the dependence of the electron energy on the frequency of the incident light. The second experiment will also allow you to determine Planck's constant and the work function of the metal used in the photodiode.

The light source used in this experiment is a mercury-vapor tube. Like all excited gases, the mercury vapor in this tube does not produce a continuous spectrum of light, but instead produces narrow spectral lines only at certain wavelengths. For this experiment, we will use five different spectral lines of mercury. The wavelength values are given in the manual for the apparatus. Note: the white mask on the h/e apparatus is made of a fluorescent material to enable you to see the ultraviolet line.

To separate the light in each of these lines, the light from the mercury vapor is passed through a diffraction grating. The line pattern in this grating causes light of different wavelengths to interfere constructively at different angles. The relationship between the wavelength of the light and the angle of constructive interference is given by

$$d \sin\theta = m\lambda \quad (m = 1, 2, 3, \ldots)$$

where d is the spacing between the enscribed lines on the grating and m is the order number of the maxima. Two filters (a yellow and a green) are included in order to prevent room light from affecting the results when the yellow and green lines are used.

You also have a variable transmission filter that will let you vary the intensity of the light without changing the wavelength.

The h/e apparatus will measure the stopping potential by allowing electrons ejected from the emitter to charge up a small capacitor. When the voltage on this capacitor equals the stopping potential, the current through the photodiode falls to zero and the voltage output of the h/e apparatus reaches a stable value. This value, read by a digital voltmeter, is approximately the stopping potential. The reason this is only *approximately* the stopping potential is that, as the ejected electrons build up charge on the capacitor, some of the previously stored charge may leak away. Thus, depending on the experimental parameters, there may be a small difference between the output voltage of the h/e apparatus and the true stopping potential.

Examine the various pieces of the apparatus. On the h/e apparatus containing the photodiode, gently roll the cylindrical light shield away from the aperture so that you can see inside. Darken the room so that you can easily see the spectral lines produced by the light source and diffraction grating. Now rotate the h/e apparatus about the pin in the coupling arm so that the light from one of the spectral lines falls on the aperture. You may notice a difference in brightness between the lines on one side and on the other side (this is due to the diffraction grating's construction)—if so, choose the brighter side. If necessary, rotate the apparatus so that the light entering through the aperture falls on the two small squares on the white photodiode mask.

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Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

Experiment #1: Relationship of Light Intensity and Ejected Electron Energy
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Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results.

Use your measurements along with Equation (5) to determine the values of Planck's constant (h) and the work function (ϕ) for the metal in the photodiode used in the h/e apparatus. Make an appropriate plot of the data and fit it with a straight line, and use the slope and intercept (with their uncertainties) to find values for $h \pm \Delta h$ and for $\varphi \pm \Delta\varphi$.

In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?

Physics 220 Lab - Spring 2009
Lab 5: The Photoelectric Effect

Introduction

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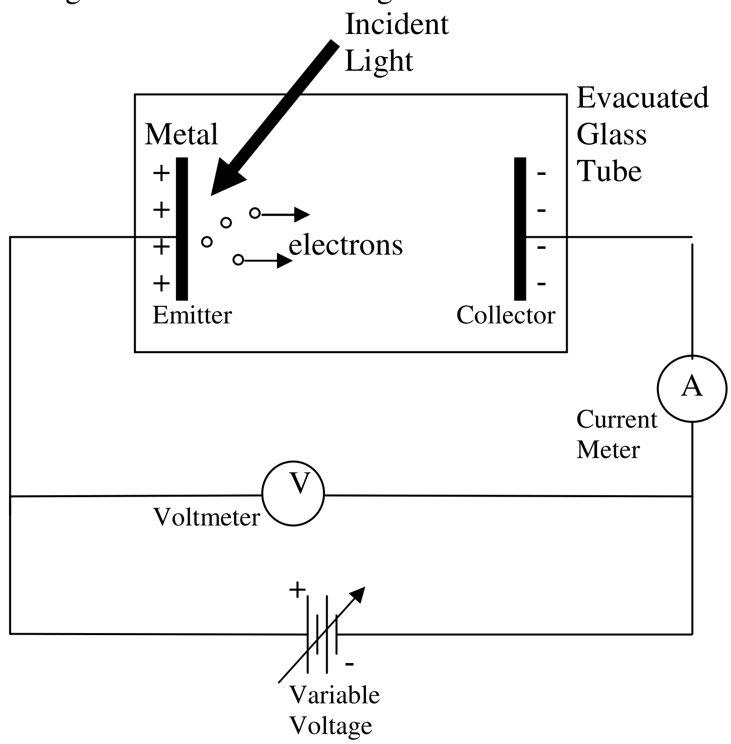

In the classical analysis of this interaction, the energy of the electrons knocked loose from the metal surface is expected to increase if the intensity (amplitude) of the light wave is increased. Thus brighter light (of any color or frequency) should produce electrons with more kinetic energy, and dimmer light should produce electrons with less kinetic energy.

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Pre-lab questions:

1. What are the slope and y-intercept of a plot with stopping potential on the vertical axis and frequency on the horizontal axis?

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Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
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Experimental Overview and Detailed Procedures

This lab consists of two experiments, the first to investigate the relationship between the intensity of the light source and the kinetic energy of the ejected electrons, and the second to determine the dependence of the electron energy on the frequency of the incident light. The second experiment will also allow you to determine Planck's constant and the work function of the metal used in the photodiode.

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Physics 220 Lab - Spring 2009

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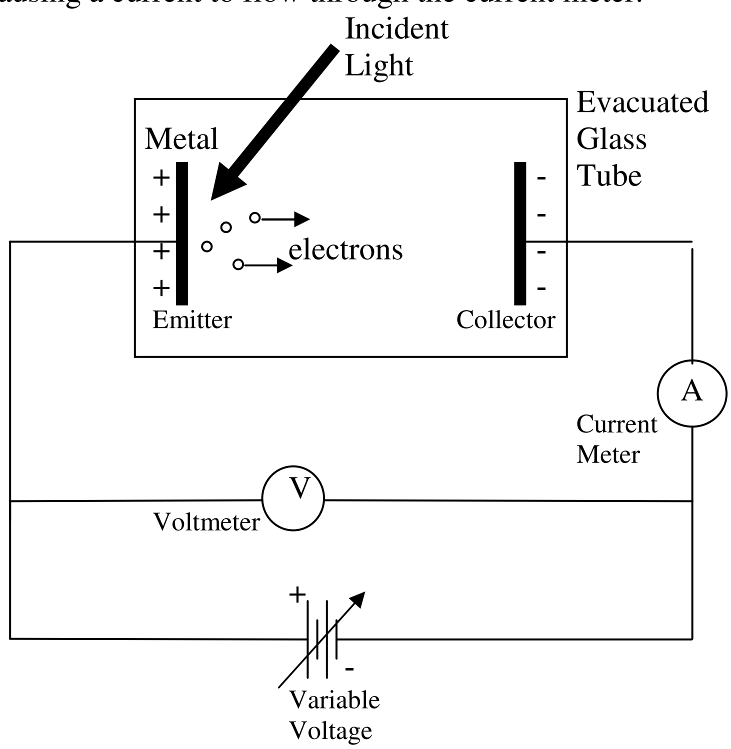

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Investigate the effects of changing the intensity while keeping the wavelength constant.

Investigate the effects of changing the wavelength while keeping the intensity constant.

Set the wavelength to a value at which there's a current flowing. Wavelength chosen: _______
Try to stop the current by changing the battery voltage. Battery voltage at which the current goes to zero: ________.

Repeat for a shorter wavelength to see how the battery voltage needed to stop the current depends on the wavelength of the incident light.

Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
- How does the maximum kinetic energy of the emitted electrons depend on the intensity of the light?
- What is the role of the voltage provided by the battery in this experiment? (What does this voltage allow you to measure?)

Experimental Overview and Detailed Procedures

This lab consists of two experiments, the first to investigate the relationship between the intensity of the light source and the kinetic energy of the ejected electrons, and the second to determine the dependence of the electron energy on the frequency of the incident light. The second experiment will also allow you to determine Planck's constant and the work function of the metal used in the photodiode.

The light source used in this experiment is a mercury-vapor tube. Like all excited gases, the mercury vapor in this tube does not produce a continuous spectrum of light, but instead produces narrow spectral lines only at certain wavelengths. For this experiment, we will use five different spectral lines of mercury. The wavelength values are given in the manual for the apparatus. Note: the white mask on the h/e apparatus is made of a fluorescent material to enable you to see the ultraviolet line.

To separate the light in each of these lines, the light from the mercury vapor is passed through a diffraction grating. The line pattern in this grating causes light of different wavelengths to interfere constructively at different angles. The relationship between the wavelength of the light and the angle of constructive interference is given by

$$d \sin\theta = m\lambda \quad (m = 1, 2, 3, \ldots)$$

where d is the spacing between the enscribed lines on the grating and m is the order number of the maxima. Two filters (a yellow and a green) are included in order to prevent room light from affecting the results when the yellow and green lines are used.

You also have a variable transmission filter that will let you vary the intensity of the light without changing the wavelength.

The h/e apparatus will measure the stopping potential by allowing electrons ejected from the emitter to charge up a small capacitor. When the voltage on this capacitor equals the stopping potential, the current through the photodiode falls to zero and the voltage output of the h/e apparatus reaches a stable value. This value, read by a digital voltmeter, is approximately the stopping potential. The reason this is only *approximately* the stopping potential is that, as the ejected electrons build up charge on the capacitor, some of the previously stored charge may leak away. Thus, depending on the experimental parameters, there may be a small difference between the output voltage of the h/e apparatus and the true stopping potential.

Examine the various pieces of the apparatus. On the h/e apparatus containing the photodiode, gently roll the cylindrical light shield away from the aperture so that you can see inside. Darken the room so that you can easily see the spectral lines produced by the light source and diffraction grating. Now rotate the h/e apparatus about the pin in the coupling arm so that the light from one of the spectral lines falls on the aperture. You may notice a difference in brightness between the lines on one side and on the other side (this is due to the diffraction grating's construction)—if so, choose the brighter side. If necessary, rotate the apparatus so that the light entering through the aperture falls on the two small squares on the white photodiode mask.

Make sure that only one of the spectral lines falls on the opening of the photodiode mask. Move the diffraction grating to focus the line on the mask. If you select the green or yellow spectral line, place the corresponding colored filter over the aperture of the h/e apparatus to block any other wavelengths of light.

Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

Experiment #1: Relationship of Light Intensity and Ejected Electron Energy
Design an experiment to investigate whether the maximum kinetic energy of the ejected electrons depends on the intensity of the light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results.

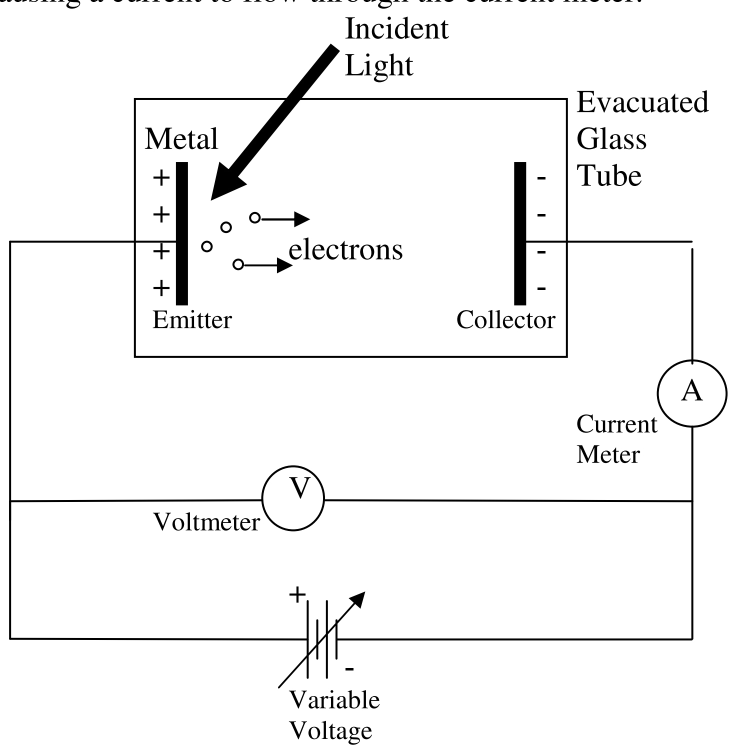
Use your measurements along with Equation (5) to determine the values of Planck's constant (h) and the work function (ϕ) for the metal in the photodiode used in the h/e apparatus. Make an appropriate plot of the data and fit it with a straight line, and use the slope and intercept (with their uncertainties) to find values for $h \pm \Delta h$ and for $\varphi \pm \Delta\varphi$.

In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?

Physics 220 Lab - Spring 2009
Lab 5: The Photoelectric Effect

Introduction

The experimental set-up for the photoelectric effect is shown in the diagram below. Light falls on a metal surface inside an evacuated glass tube. The light strikes the surface of the metal, transferring their energy to some of the electrons in the metal. The kinetic energy gained by the electrons may allow some to escape from the surface. Some of these ejected electrons will travel across the tube to the collector, causing a current to flow through the current meter.



In the classical analysis of this interaction, the energy of the electrons knocked loose from the metal surface is expected to increase if the intensity (amplitude) of the light wave is increased. Thus brighter light (of any color or frequency) should produce electrons with more kinetic energy, and dimmer light should produce electrons with less kinetic energy.

In quantum theory, the energy of the incident photons depends only on the *frequency* of the light, through the relation

$$E_{photon} = hf \qquad (1)$$

where h is Planck's constant and f is the frequency of the light. Allowing for the loss of kinetic energy as the electrons escape from the surface, Einstein predicted the maximum kinetic energy of the ejected electrons to be

$$KE_{max} = hf - \phi \qquad (2)$$

where ϕ is the work function of the metal from which the electrons are ejected.

To determine the kinetic energy of the ejected electrons, a voltage source is used to induce a positive charge on the emitter and a negative charge on the collector. The electric field produced by these charges opposes the flow of electrons between the emitter and the collector. When the voltage is high enough, the electrons return to the metal plate (the emitter) rather than traveling to the collector.

The voltage at which the electric current between the emitter and the collector is stopped is called the "stopping potential." The stopping potential (ΔV_s) is related to the maximum kinetic energy of the electrons through the relation

$$KE_{max} = e\Delta V_s \qquad (3)$$

where e is the charge on the electron.

Combining Equations (2) and (3), we have

$$e\Delta V_s = hf - \phi \qquad (4)$$

or

$$\Delta V_s = (h/e)f - \phi/e \qquad (5)$$

Pre-lab questions:

1. What are the slope and y-intercept of a plot with stopping potential on the vertical axis and frequency on the horizontal axis?

2. In order to help you visualize what's going on in the photoelectric effect experiment, take a look at a simulation.
Go to http://phet.colorado.edu/simulations/ and click on Quantum Phenomena, and then open the Photoelectric Effect simulation. Run this simulation.

Check the box to Show only highest energy electrons. Make sure the target is sodium.
Set the wavelength to about 500 nm
Set the battery voltage to 0.00 V
Set the intensity to about 50%
and observe what happens to the current and to the speed (kinetic energy) of the electrons.

Investigate the effects of changing the intensity while keeping the wavelength constant.

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Repeat for a shorter wavelength to see how the battery voltage needed to stop the current depends on the wavelength of the incident light.

Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
- How does the maximum kinetic energy of the emitted electrons depend on the intensity of the light?
- What is the role of the voltage provided by the battery in this experiment? (What does this voltage allow you to measure?)

Experimental Overview and Detailed Procedures

This lab consists of two experiments, the first to investigate the relationship between the intensity of the light source and the kinetic energy of the ejected electrons, and the second to determine the dependence of the electron energy on the frequency of the incident light. The second experiment will also allow you to determine Planck's constant and the work function of the metal used in the photodiode.

The light source used in this experiment is a mercury-vapor tube. Like all excited gases, the mercury vapor in this tube does not produce a continuous spectrum of light, but instead produces narrow spectral lines only at certain wavelengths. For this experiment, we will use five different spectral lines of mercury. The wavelength values are given in the manual for the apparatus. Note: the white mask on the h/e apparatus is made of a fluorescent material to enable you to see the ultraviolet line.

To separate the light in each of these lines, the light from the mercury vapor is passed through a diffraction grating. The line pattern in this grating causes light of different wavelengths to interfere constructively at different angles. The relationship between the wavelength of the light and the angle of constructive interference is given by

$$d \sin\theta = m\lambda \quad (m = 1, 2, 3, \ldots)$$

where d is the spacing between the enscribed lines on the grating and m is the order number of the maxima. Two filters (a yellow and a green) are included in order to prevent room light from affecting the results when the yellow and green lines are used.

You also have a variable transmission filter that will let you vary the intensity of the light without changing the wavelength.

The h/e apparatus will measure the stopping potential by allowing electrons ejected from the emitter to charge up a small capacitor. When the voltage on this capacitor equals the stopping potential, the current through the photodiode falls to zero and the voltage output of the h/e apparatus reaches a stable value. This value, read by a digital voltmeter, is approximately the stopping potential. The reason this is only *approximately* the stopping potential is that, as the ejected electrons build up charge on the capacitor, some of the previously stored charge may leak away. Thus, depending on the experimental parameters, there may be a small difference between the output voltage of the h/e apparatus and the true stopping potential.

Examine the various pieces of the apparatus. On the h/e apparatus containing the photodiode, gently roll the cylindrical light shield away from the aperture so that you can see inside. Darken the room so that you can easily see the spectral lines produced by the light source and diffraction grating. Now rotate the h/e apparatus about the pin in the coupling arm so that the light from one of the spectral lines falls on the aperture. You may notice a difference in brightness between the lines on one side and on the other side (this is due to the diffraction grating's construction)—if so, choose the brighter side. If necessary, rotate the apparatus so that the light entering through the aperture falls on the two small squares on the white photodiode mask.

Make sure that only one of the spectral lines falls on the opening of the photodiode mask. Move the diffraction grating to focus the line on the mask. If you select the green or yellow spectral line, place the corresponding colored filter over the aperture of the h/e apparatus to block any other wavelengths of light.

Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

Experiment #1: Relationship of Light Intensity and Ejected Electron Energy

Design an experiment to investigate whether the maximum kinetic energy of the ejected electrons depends on the intensity of the light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results.

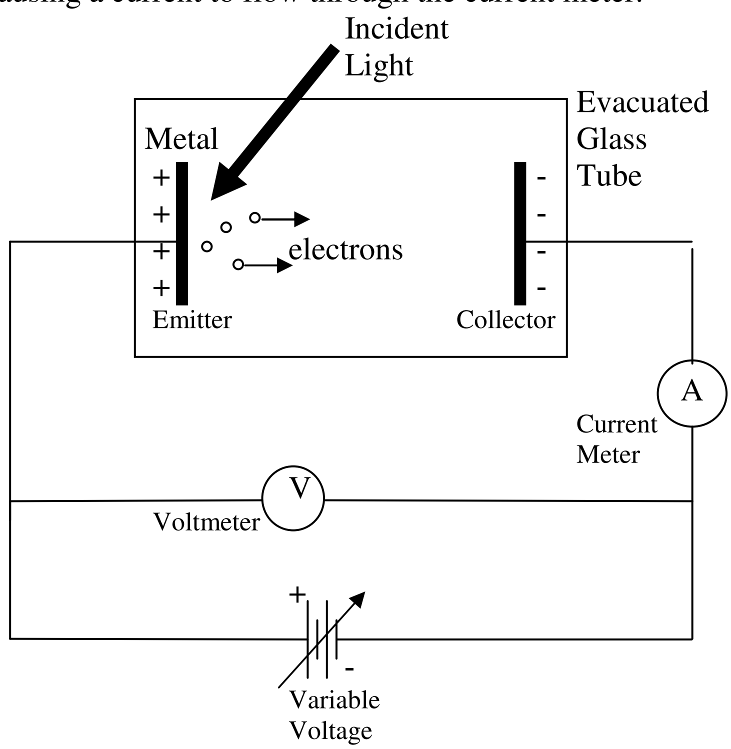
Use your measurements along with Equation (5) to determine the values of Planck's constant (h) and the work function (ϕ) for the metal in the photodiode used in the h/e apparatus. Make an appropriate plot of the data and fit it with a straight line, and use the slope and intercept (with their uncertainties) to find values for $h \pm \Delta h$ and for $\varphi \pm \Delta\varphi$.

In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?

Physics 220 Lab - Spring 2009
Lab 5: The Photoelectric Effect

Introduction

The experimental set-up for the photoelectric effect is shown in the diagram below. Light falls on a metal surface inside an evacuated glass tube. The light strikes the surface of the metal, transferring their energy to some of the electrons in the metal. The kinetic energy gained by the electrons may allow some to escape from the surface. Some of these ejected electrons will travel across the tube to the collector, causing a current to flow through the current meter.



In the classical analysis of this interaction, the energy of the electrons knocked loose from the metal surface is expected to increase if the intensity (amplitude) of the light wave is increased. Thus brighter light (of any color or frequency) should produce electrons with more kinetic energy, and dimmer light should produce electrons with less kinetic energy.

In quantum theory, the energy of the incident photons depends only on the *frequency* of the light, through the relation

$$E_{photon} = hf \qquad (1)$$

where h is Planck's constant and f is the frequency of the light. Allowing for the loss of kinetic energy as the electrons escape from the surface, Einstein predicted the maximum kinetic energy of the ejected electrons to be

$$KE_{max} = hf - \phi \qquad (2)$$

where ϕ is the work function of the metal from which the electrons are ejected.

To determine the kinetic energy of the ejected electrons, a voltage source is used to induce a positive charge on the emitter and a negative charge on the collector. The electric field produced by these charges opposes the flow of electrons between the emitter and the collector. When the voltage is high enough, the electrons return to the metal plate (the emitter) rather than traveling to the collector.

The voltage at which the electric current between the emitter and the collector is stopped is called the "stopping potential." The stopping potential (ΔV_s) is related to the maximum kinetic energy of the electrons through the relation

$$KE_{max} = e\Delta V_s \qquad (3)$$

where e is the charge on the electron.

Combining Equations (2) and (3), we have

$$e\Delta V_s = hf - \phi \qquad (4)$$

or

$$\Delta V_s = (h/e)f - \phi/e \qquad (5)$$

Pre-lab questions:

1. What are the slope and y-intercept of a plot with stopping potential on the vertical axis and frequency on the horizontal axis?

2. In order to help you visualize what's going on in the photoelectric effect experiment, take a look at a simulation.
Go to http://phet.colorado.edu/simulations/ and click on Quantum Phenomena, and then open the Photoelectric Effect simulation. Run this simulation.

Check the box to Show only highest energy electrons. Make sure the target is sodium.
Set the wavelength to about 500 nm
Set the battery voltage to 0.00 V
Set the intensity to about 50%
and observe what happens to the current and to the speed (kinetic energy) of the electrons.

Investigate the effects of changing the intensity while keeping the wavelength constant.

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Set the wavelength to a value at which there's a current flowing. Wavelength chosen: _______
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Repeat for a shorter wavelength to see how the battery voltage needed to stop the current depends on the wavelength of the incident light.

Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
- How does the maximum kinetic energy of the emitted electrons depend on the intensity of the light?
- What is the role of the voltage provided by the battery in this experiment? (What does this voltage allow you to measure?)

Experimental Overview and Detailed Procedures

This lab consists of two experiments, the first to investigate the relationship between the intensity of the light source and the kinetic energy of the ejected electrons, and the second to determine the dependence of the electron energy on the frequency of the incident light. The second experiment will also allow you to determine Planck's constant and the work function of the metal used in the photodiode.

The light source used in this experiment is a mercury-vapor tube. Like all excited gases, the mercury vapor in this tube does not produce a continuous spectrum of light, but instead produces narrow spectral lines only at certain wavelengths. For this experiment, we will use five different spectral lines of mercury. The wavelength values are given in the manual for the apparatus. Note: the white mask on the h/e apparatus is made of a fluorescent material to enable you to see the ultraviolet line.

To separate the light in each of these lines, the light from the mercury vapor is passed through a diffraction grating. The line pattern in this grating causes light of different wavelengths to interfere constructively at different angles. The relationship between the wavelength of the light and the angle of constructive interference is given by

$$d \sin\theta = m\lambda \qquad (m = 1, 2, 3, \ldots)$$

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You also have a variable transmission filter that will let you vary the intensity of the light without changing the wavelength.

The h/e apparatus will measure the stopping potential by allowing electrons ejected from the emitter to charge up a small capacitor. When the voltage on this capacitor equals the stopping potential, the current through the photodiode falls to zero and the voltage output of the h/e apparatus reaches a stable value. This value, read by a digital voltmeter, is approximately the stopping potential. The reason this is only *approximately* the stopping potential is that, as the ejected electrons build up charge on the capacitor, some of the previously stored charge may leak away. Thus, depending on the experimental parameters, there may be a small difference between the output voltage of the h/e apparatus and the true stopping potential.

Examine the various pieces of the apparatus. On the h/e apparatus containing the photodiode, gently roll the cylindrical light shield away from the aperture so that you can see inside. Darken the room so that you can easily see the spectral lines produced by the light source and diffraction grating. Now rotate the h/e apparatus about the pin in the coupling arm so that the light from one of the spectral lines falls on the aperture. You may notice a difference in brightness between the lines on one side and on the other side (this is due to the diffraction grating's construction)—if so, choose the brighter side. If necessary, rotate the apparatus so that the light entering through the aperture falls on the two small squares on the white photodiode mask.

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Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

Experiment #1: Relationship of Light Intensity and Ejected Electron Energy
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Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

Carry out the experiment and record the procedure, data, and results.

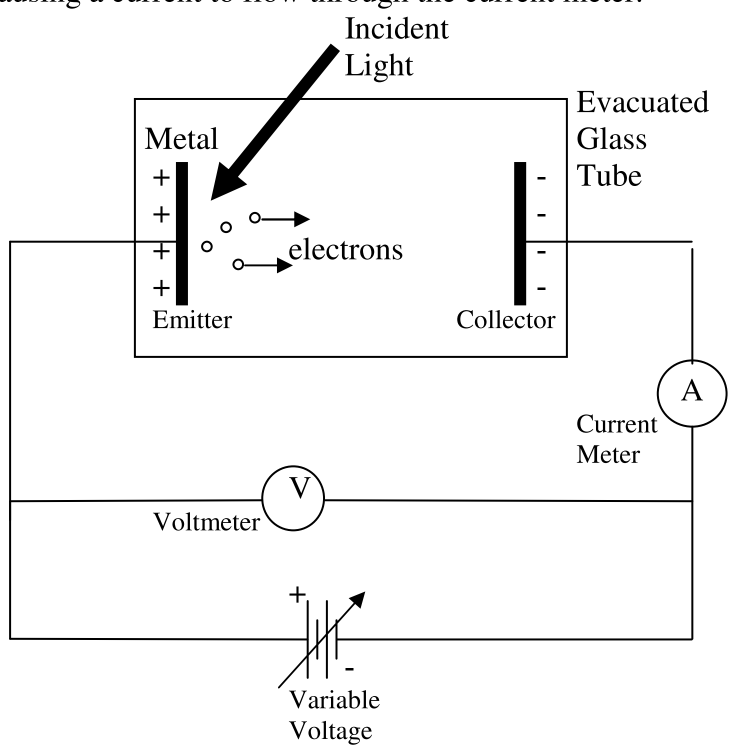
Use your measurements along with Equation (5) to determine the values of Planck's constant (h) and the work function (ϕ) for the metal in the photodiode used in the h/e apparatus. Make an appropriate plot of the data and fit it with a straight line, and use the slope and intercept (with their uncertainties) to find values for $h \pm \Delta h$ and for $\varphi \pm \Delta\varphi$.

In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?

Physics 220 Lab - Spring 2009
Lab 5: The Photoelectric Effect

Introduction

The experimental set-up for the photoelectric effect is shown in the diagram below. Light falls on a metal surface inside an evacuated glass tube. The light strikes the surface of the metal, transferring their energy to some of the electrons in the metal. The kinetic energy gained by the electrons may allow some to escape from the surface. Some of these ejected electrons will travel across the tube to the collector, causing a current to flow through the current meter.



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Pre-lab questions:

1. What are the slope and y-intercept of a plot with stopping potential on the vertical axis and frequency on the horizontal axis?

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Summarize in your logbook:

- How does the maximum kinetic energy of the emitted electrons depend on the wavelength of the light?
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Experimental Overview and Detailed Procedures

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Make sure that only one of the spectral lines falls on the opening of the photodiode mask. Move the diffraction grating to focus the line on the mask. If you select the green or yellow spectral line, place the corresponding colored filter over the aperture of the h/e apparatus to block any other wavelengths of light.

Turn on the power to the h/e apparatus and connect and turn on the digital multimeter if it's not already on. Press and hold the "Push to zero" button on the h/e apparatus to release any stored charge on the internal capacitor. Then release the "Push to zero" button and note that the output voltage of the h/e apparatus quickly builds up to a stable value. Always make sure you wait for the voltage to stabilize before recording the value of the stopping voltage.

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Carry out the experiment and record the procedure, data, and results. Summarize: do your results support the classical model (in which the kinetic energy increases with intensity)?

Experiment #2: Relationship of Light Wavelength (Frequency) and Ejected Electron Energy; Determination of Planck's Constant and Work Function

Design an experiment to investigate the relationship between the maximum kinetic energy of the ejected electrons and the wavelength of the incident light. When you have a proposed experiment (including what you're going to measure, how you're going to measure it, and how you will obtain results along with uncertainties), check with me to get approval to carry out the experiment.

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In your summary, compare your measured value of h to the accepted value. Also look at the table of work functions for some common elements. Is it likely that the cathode is one of these elements?