

# ملخص الدرس الثاني wave Matter من الوحدة 22 MODULE Theory Quantum انسباير منهج and the Atom



## تم تحميل هذا الملف من موقع المناهج الإماراتية

موقع المناهج ← المناهج الإماراتية ← الصف الثاني عشر المتقدم ← فيزياء ← الفصل الثالث ← ملفات متنوعة ← الملف

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ملفات اكتب للمعلم اكتب للطالب | اختبارات الكترونية | اختبارات | حلول | عروض بوربوينت | أوراق عمل  
منهج انجليزي | ملخصات وتقارير | مذكرات وبنوك | الامتحان النهائي للمدرس

المزيد من مادة  
فيزياء:

إعداد: Atef Mohamed

## التواصل الاجتماعي بحسب الصف الثاني عشر المتقدم



صفحة المناهج  
الإماراتية على  
فيسبوك

الرياضيات

اللغة الانجليزية

اللغة العربية

التربية الاسلامية

المواد على تلغرام

## المزيد من الملفات بحسب الصف الثاني عشر المتقدم والمادة فيزياء في الفصل الثالث

ملخص الدرس الأول wave of model particle A من الوحدة 22 MODULE Theory Quantum and the Atom  
انسباير منهج

1

مراجعة الوحدة الخامسة التيار والمقاومة منهج بريدج Bridge

2

تجميعه جميع قوانين المادة الفصل الثالث منهج بريدج

3

تجميعه نهائية مهمة جداً لاختبار الإعادة

4

بعض أسئلة الامتحان النهائي القسم الالكتروني مع تدريبات إضافية

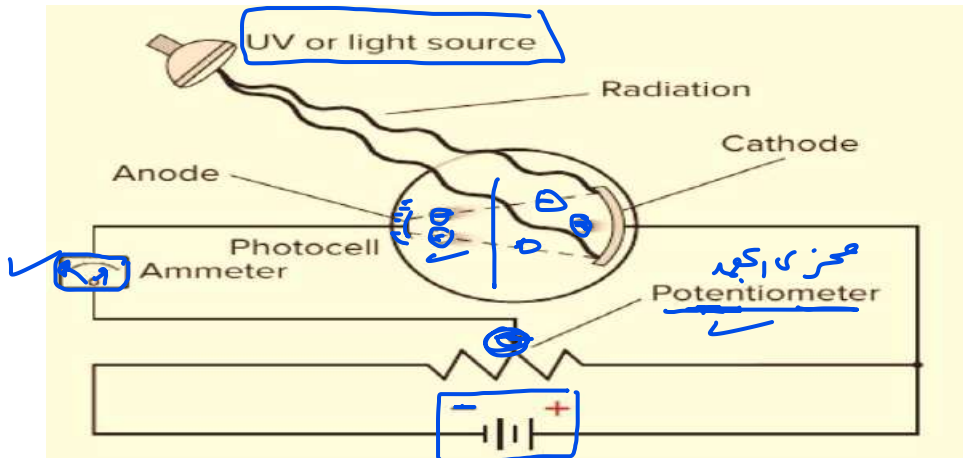
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# QUANTUM THEORY AND THE ATOM

## Einstein's Theory Test

### How can the kinetic energy of emitted electrons be measured?

This can be done using the electric circuit shown, which consists of a photoelectric cell connected to a galvanometer, a variable voltage source, and a voltmeter to control the applied potential difference.



$$KE = W$$

$$KE = -qV_0$$

$$KE = qV_0$$

Steps:

1. The photoelectric cell is connected to the battery so that the anode is connected to the negative terminal and the cathode to the positive terminal.
2. The cathode is exposed to suitable electromagnetic radiation (light or UV). A deflection appears on the galvanometer, indicating that an electric current is flowing.
3. The reverse (stopping) voltage is gradually increased in the circuit. As the stopping voltage increases, the current decreases because fewer electrons reach the anode.
4. The reverse voltage is increased further until the current becomes zero. The stopping voltage at which the current becomes zero is called the **stopping potential**  $V_0$ .
5. At the stopping potential, the maximum kinetic energy of the electrons equals the work done by the electric field in stopping them, meaning:

- ✓ يتم توصيل الخلية الكهروضوئية بالبطارية بحيث يكون المصعد (الأنود) متصلاً بالطرف السالب، والمهبط (الكاثود) متصلاً بالطرف الموجب.
- ✓ يُعرّض المهبط لإشعاع كهرومغناطيسي مناسب (ضوء أو أشعة فوق بنفسجية).  $f > f_0$
- ✓ يظهر انحراف في الجلفانومتر، مما يدل على مرور تيار كهربائي.
- ✓ يتم زيادة الجهد العكسي (جهد الإيقاف) تدريجياً في الدائرة.
- ✓ مع زيادة جهد الإيقاف، يقل التيار لأن عدداً أقل من الإلكترونات يصل إلى المصعد.
- ✓ يستمر زيادة الجهد العكسي حتى يصبح التيار صفراً.
- ✓ يُسمى الجهد الذي عنده ينعدم التيار جهد الإيقاف  $V_0$ .

□ عند جهد الإيقاف، تكون أقصى طاقة حركية للإلكترونات مساوية للشغل المبذول بواسطة المجال الكهربائي لإيقافها، أي:

$$KE = -qV_0 = \frac{1}{2}mv^2$$

$$KE = qV_0 = \frac{1}{2}mv^2$$

- $KE$ : maximum kinetic energy of the emitted electron (J)
- $q$ : charge of the electron =  $-1.6 \times 10^{-19}$  " " C
- $V_0$ : stopping potential (V)
- $v$ : speed of the electron (m/s)



# QUANTUM THEORY AND THE ATOM

## Important Notes:

1. The speed of the electrons after being emitted is different because they collide with atoms before exiting. Therefore, the speed of electrons near the surface is greater than the speed of electrons in the deeper layers.
2. When the stopping potential is applied, the fastest electrons cannot reach the anode. Therefore, the electric current becomes zero.

1. تختلف سرعة الإلكترونات بعد انبعاثها لأنها تصطدم بذرات قبل خروجها. لذلك تكون سرعة الإلكترونات القريبة من السطح أكبر من سرعة الإلكترونات في الطبقات الأعمق.
2. عند تطبيق جهد الإيقاف، لا تستطيع أسرع الإلكترونات الوصول إلى المصعد. لذلك يصبح التيار الكهربائي صفراً.

## How can the energy of a photon be measured practically?

**A:** By measuring the kinetic energy of the emitted electrons from the surface of a metal when exposed to two different wavelengths, or by measuring the kinetic energy of the emitted electrons from a known metal at a specific wavelength.

كيف يمكن قياس طاقة الفوتون عملياً؟  
يمكن قياسها عن طريق قياس الطاقة الحركية للإلكترونات المنبعثة من سطح معدن عند تعريضه لطولين موجيين مختلفين، أو عن طريق قياس الطاقة الحركية للإلكترونات المنبعثة من معدن معلوم عند طول موجي معين.

## Application of the Photoelectric Effect: Digital Cameras

Digital cameras rely on a variation of the photoelectric effect called the **photovoltaic effect**. They use a grid of millions of tiny sensors (photoelectric detectors) packed into a very small area to convert light into electrical data.

### Summary of the Process (Step-by-Step)

1. **The Filter Grid:**  
Before reaching the sensor, light passes through a grid of color filters. Each filter allows only specific wavelengths (colors) to pass.
  1. **Note:** There are more **green filters** in the grid because human eyes are naturally more sensitive to green light.
2. **Photon-to-Electron Conversion:**  
When particles of light (**photons**) strike the **detector**, they release **electrons**. These **photoelectrons** are stored as an electrical charge. The amount of charge represents the **brightness** of the light at that specific point.
3. **Digital Reconstruction:**  
The camera's internal circuitry collects data from all detectors. By analyzing the charge from adjacent detectors, the computer determines the precise color and intensity for every **pixel** in the final image.

## تطبيق الظاهرة الكهروضوئية: الكاميرا الرقمية

تعتمد الكاميرات الرقمية في جوهرها على "مستشعرات ضوئية" صلبة جداً (بالملايين) لتحويل الضوء إلى صور رقمية. هذه العملية هي نوع من أنواع الظاهرة الكهروضوئية تُعرف باسم "الأثر الكهروضوئي الجهدية" (**Photovoltaic effect**).

منخفض آلية العمل (حسب الأرقام في الصورة):

1. **شبكة المرشحات (Filters):**  
يمر الضوء أولاً عبر شبكة من المرشحات الملونة. هذه المرشحات تسمح فقط لأطوال موجية محددة (ألوان معينة) بالمرور لكل مستشعر.
  1. **ملاحظة ذكية:** توجد مرشحات للون الأخضر أكثر من غيرها، لأن العين البشرية أكثر حساسية لهذا اللون.
2. **المستشعر الكهروضوئي (Detector):**  
عندما تصطدم جسيمات الضوء (**الفوتونات**) بالمستشعر، فإنها تحرر إلكترونات، مما يؤدي إلى تخزين شحنة كهربائية كمية الشحنة المخزنة تعبر عن مدى "سطوع" الضوء في تلك النقطة.
3. **المعالجة الرقمية (Processing):**  
تقوم الدوائر الإلكترونية في الكاميرا بتجميع البيانات من ملايين المستشعرات، وتستخدم خوارزميات لدمج الألوان من المستشعرات المجاورة لتحديد اللون النهائي لكل بكسل (**Pixel**) في الصورة.



# QUANTUM THEORY AND THE ATOM

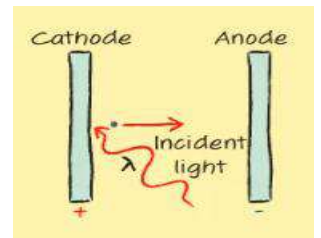
## Applications of the Photoelectric Effect

Examples:

Application	Explanation
Solar cells ✓	Use the photoelectric effect to convert sunlight into electrical energy.
Automatic doors ✓	Use infrared beams; when the beam is interrupted, the current changes and the door opens.
Car headlights ✓	When the light beam is blocked (e.g., by smoke), the current decreases, triggering automatic responses.
Lighting control ✓	The photoelectric effect is used to automatically switch street lights on and off depending on light intensity (day/night).

## Photoelectron Kinetic Energy

A certain photocell has a stopping potential difference of  $4.0 \text{ V}$ .  
How much kinetic energy does the incident light give the emitted electrons?  
Give your answer in both **joules (J)** and **electron volts (eV)**.



تمتلك خلية كهروضوئية معينة جهد إيقاف مقداره  $4.0$  فولت.

كم مقدار الطاقة الحركية التي يعطيها الضوء الساقط للإلكترونات المنبعثة؟

اكتب إجابتك بوحدتي:

- الجول (J)
- والإلكترون فولت (eV)

$$KE = qV_0 = 1.6 \times 10^{-19} \times 4 = 6.4 \times 10^{-19} \text{ J}$$

$$KE = qV_0 = [e] \times 4 = 4 \text{ eV}$$



# QUANTUM THEORY AND THE ATOM

5. An electron has an energy of 2.3 eV. What is the kinetic energy of the electron in joules?

6. What is the velocity of the electron in the previous problem?

7. What is the kinetic energy in eV of an electron with a velocity of  $6.2 \times 10^6$  m/s?

8. The stopping potential for a photoelectric cell is  $5.7$  V. Calculate the maximum kinetic energy of the emitted photoelectrons in eV.

9. The stopping potential for a photoelectric cell is  $5.1$  V. How much kinetic energy does the incident light give the electrons in joules?

10. The maximum kinetic energy of emitted photoelectrons in a photoelectric cell is  $7.5 \times 10^{-19}$  J. What is the stopping potential?

11. **CHALLENGE** The stopping potential required to prevent current through a photocell is  $3.2$  V. Calculate the maximum kinetic energy in joules of the photoelectrons as they are emitted.

$$5) KE = 2.3 \text{ eV} \times 1.6 \times 10^{-19} = 3.68 \times 10^{-19} \text{ (J)}$$

$$6) KE = \frac{1}{2} m v^2 \quad 3.68 \times 10^{-19} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 \quad v = \text{ m/s}$$

$$7) KE = \frac{1}{2} m v^2 = \frac{1}{2} \times 9.11 \times 10^{-31} \times (6.2 \times 10^6)^2 = \frac{1.75 \times 10^{-17} \text{ J}}{1.6 \times 10^{-19}} = 109 \text{ eV}$$

$$8) KE = q V_0 = e \times 5.7 = 5.7 \text{ eV}$$

$$9) KE = q V_0 = 1.6 \times 10^{-19} \times 5.1 = \text{ (J)}$$

$$10) KE = q V_0 \quad 7.5 \times 10^{-19} = 1.6 \times 10^{-19} \times V_0 \quad V_0 =$$

$$11) KE = q V_0 = 1.6 \times 10^{-19} \times 3.2 = \text{ (J)}$$

**WORK FUNCTION AND ENERGY** A particular photocell uses a sodium cathode. Sodium has a threshold wavelength of  $526$  nm.

a. Find the work function of sodium in eV.  $W = \frac{1240}{526} = 2.35 \text{ eV}$

b. If ultraviolet radiation with a wavelength of  $348$  nm falls on sodium, will the cathode discharge electrons? If so, what is the maximum energy of the ejected electrons in eV?

## 1 ANALYZE AND SKETCH THE PROBLEM

Draw the cathode and anode, the incident radiation, and the direction of the ejected electron.

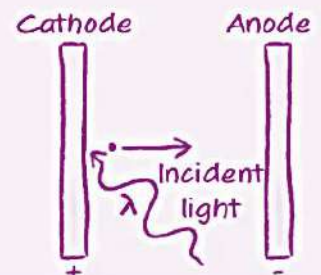
Known

$$\lambda_0 = 526 \text{ nm} \quad \lambda = 348 \text{ nm}$$

$$hc = 1240 \text{ eV} \cdot \text{nm}$$

Unknown

$$W = ? \quad KE = ?$$



$$E = \frac{1240}{348} = 3.56 \text{ eV}$$

$$KE = E - W = 3.56 - 2.35 = 1.2 \text{ (eV)}$$



# QUANTUM THEORY AND THE ATOM

12. The threshold wavelength of zinc is  $\lambda_0 = 310$  nm. Find the threshold frequency, in Hz, and the work function, in eV, of zinc.

13. The work function for cesium is  $w = 1.95$  eV. What is the maximum kinetic energy, in eV, of photoelectrons ejected when 425-nm violet light falls on the cesium?

$$12) f_0 = \frac{c}{\lambda_0} = \frac{3 \times 10^8}{310 \times 10^{-9}} = \boxed{42}$$

$$13) E = \frac{1240}{425} = 2.91 \text{ eV}$$

$$14) E = \frac{1240}{193} = 6.42 \text{ eV}$$

$$15) w = \frac{1240}{273} = 4.56 \text{ eV}$$

$\boxed{42}$

$$w = \frac{1240}{310} = \text{eV}$$

$$KE = E - w = 2.91 - 1.95 = \underline{1 \text{ eV}}$$

$$KE = E - w \rightarrow \underline{3.5} = 6.42 - w \quad w = \underline{\text{eV}}$$

$\boxed{\text{Copper}}$

14. When a metal is illuminated with 193-nm ultraviolet radiation, electrons with kinetic energies of  $3.5$  eV are emitted. What is the work function of the metal?

15. **CHALLENGE** A researcher illuminates a sample of metal and finds the longest wavelength to eject electrons is 273 nm. Find the work function. Use Table 1 to identify the most likely metal.

$\boxed{1-w}$

A photon of light has a wavelength of 620 nm.

Using the equation below, calculate the energy of the photon in electron volts (eV).



# QUANTUM THEORY AND THE ATOM

## Compton Effect

Einstein explained that light behaves like particles (photons).  
Each photon has energy and also has momentum (like a moving object).

The momentum of a photon is given by:

فسر أينشتاين أن الضوء يتصرف كأنه جسيمات (فوتونات).  
كل فوتون يمتلك طاقة وله أيضًا زخم (كمية حركة) مثل الجسم المتحرك.

ويعطى زخم الفوتون بالعلاقة:

$$p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$$

This means that even though photons have **no mass**, they still behave like objects that carry momentum.

هذا يعني أنه رغم أن الفوتونات ليس لها كتلة، إلا أنها تتصرف كأجسام تحمل زخمًا (كمية حركة).

## What Compton Did

Compton studied how X-rays collide with electrons in a material.  
He found that:

- When a photon hits an electron, it **loses some of its energy**.
- Its **wavelength becomes longer** after the collision.
- The electron gains kinetic energy and moves away.

درس كومبتون كيفية تصادم الأشعة السينية مع الإلكترونات في مادة ما. ووجد أن:

- عندما يصطدم فوتون بإلكترون، فإنه يفقد جزءًا من طاقته .
- يزداد طول الموجة بعد التصادم .
- يكتسب الإلكترون طاقة حركية وينطلق مبتعدًا .

This change in wavelength is called the **Compton Effect**

## Compton Effect (Definition)

A phenomenon where a photon scatters off an electron, causing the photon's energy to decrease and its wavelength to increase.

ظاهرة يتشتت فيها الفوتون عند اصطدامه بإلكترون، مما يؤدي إلى نقصان طاقة الفوتون وزيادة طول الموجة.



# QUANTUM THEORY AND THE ATOM

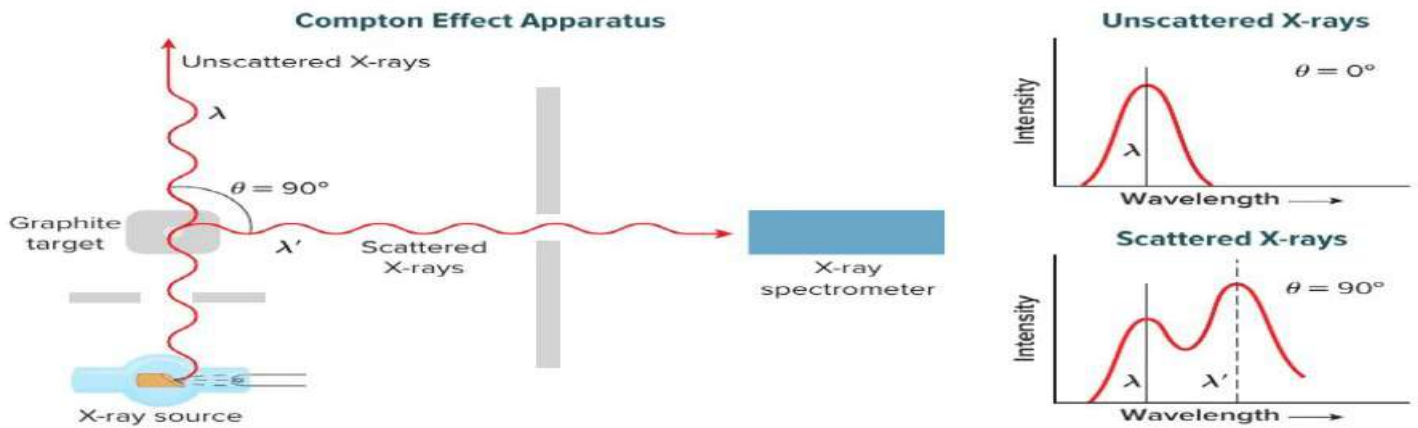
## Compton Experiment (Simplified Explanation)

Compton shined X-rays on a target and measured the wavelength before and after the collision. He found that the scattered X-ray always had a longer wavelength than the original one. This was clear proof that photons behave like particles that collide and exchange momentum.

سلط كومبتون أشعة سينية على هدف وقاس الطول الموجي قبل وبعد التصادم.

ووجد أن الأشعة السينية المتشتتة يكون لها طول موجي أكبر دائمًا من الأشعة الأصلية.

وكان هذا دليلًا واضحًا على أن الفوتونات تتصرف كأنها جسيمات تصدم وتتبادل الزخم (كمية الحركة).



## What Compton Observed in His Experiment

1. Some of the scattered X-rays did not change their wavelength.
2. Some of the scattered X-rays had a longer wavelength than the original X-rays. This increase in wavelength occurred because of collisions between photons and electrons.

بعض الأشعة السينية المتشتتة لم يتغير طولها الموجي .

بعض الأشعة السينية المتشتتة كان لها طول موجي أكبر من الأشعة الأصلية .

حدثت هذه الزيادة في الطول الموجي نتيجة تصادم الفوتونات مع الإلكترونات.

## Conclusion

The energy and momentum gained by the released electrons come from the incoming photons.

This means photons **lose part of their energy and momentum** during the collision.

In other words, photons behave like particles that collide and exchange momentum and energy.

الطاقة والزخم (كمية الحركة) التي تكتسبها الإلكترونات المنطلقة تأتي من الفوتونات الساقطة.

وهذا يعني أن الفوتونات تفقد جزءًا من طاقتها وزخمها أثناء التصادم.

بمعنى آخر، تتصرف الفوتونات كأنها جسيمات تتصادم وتتبادل الطاقة والزخم.



# QUANTUM THEORY AND THE ATOM

In a Compton experiment, a photon with wavelength 1 nm strikes an electron and the scattered photon comes out with wavelength 4 nm.

Calculate:

1. Momentum of the incident photon and the scattered photon.
2. Momentum of the electron after the collision.
3. Speed of the electron after the collision.

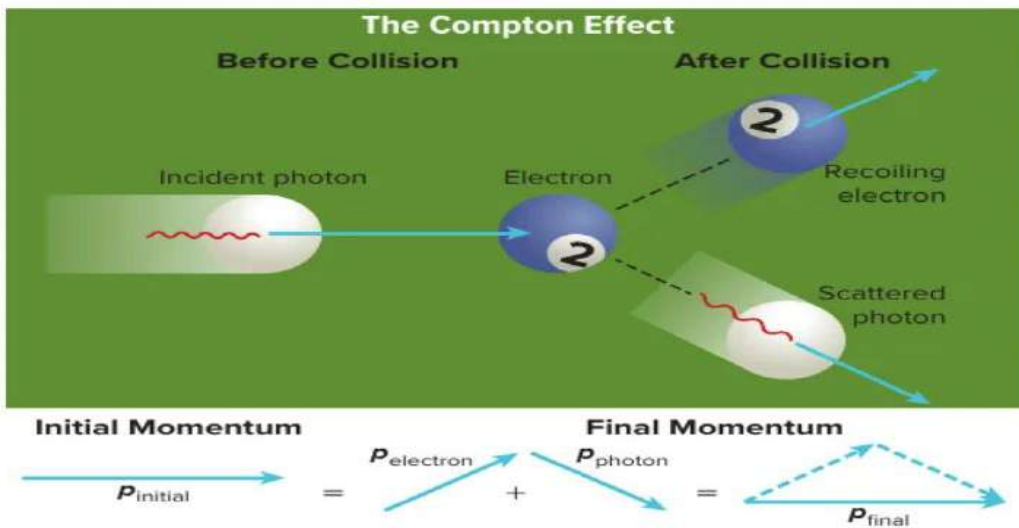
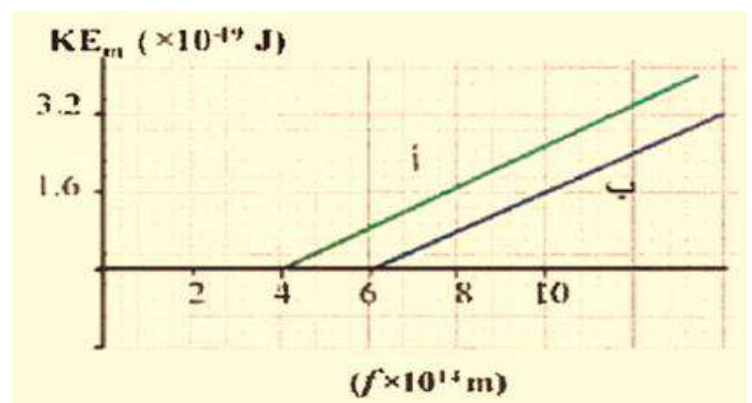


Figure 11 The laws of conservation of energy and momentum apply to collisions between billiard balls and between photons and particles.

The adjacent graph shows the relationship between the frequency of the incident light on two different metals (A and B), and the maximum kinetic energy of the emitted electrons. Based on the graph, answer the following:

- Explain why the two lines for the two metals are parallel.



# QUANTUM THEORY AND THE ATOM

• Calculate the maximum kinetic energy of the emitted electrons when light of frequency

$$4.7 \times 10^{14} \text{ Hz}$$

is shined on metal (B).

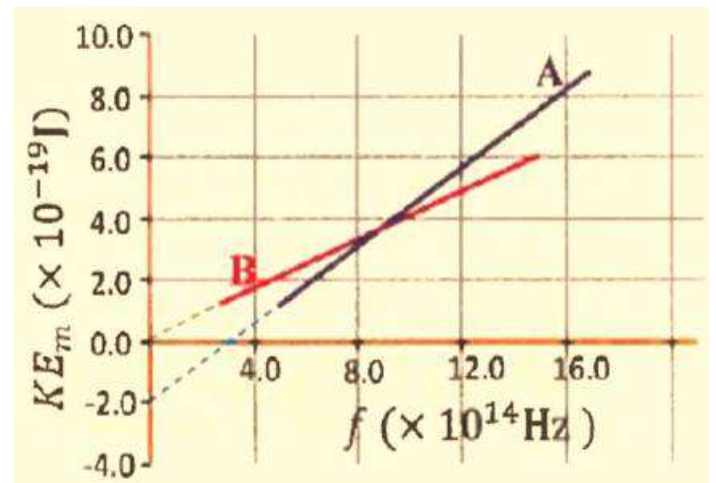
(Take  $h = 6.63 \times 10^{-34} \text{ J}\cdot\text{Hz}$ )

The line (A) in the adjacent graph correctly represents the relationship between the maximum kinetic energy of the electrons emitted from the surface of a metal and the frequency of the incident light on it, while line (B) does *not* correctly represent that relationship.

\*\*Calculate the maximum kinetic energy of the electrons emitted from the surface of the metal when light of frequency

$$2.0 \times 10^{15} \text{ Hz}$$

is incident on it.\*\*



Why does line (B) *not* represent the correct relationship between the maximum kinetic energy and the frequency of the incident light?

A light of energy 2.3 eV is shined on four different metals whose work functions are shown in the table.

Which of these metals emit electrons from their surface when the light falls on them?

Metal	a	b	c	d
Work Function (eV)	1.9	2.3	2.7	4.2

- a only
- d and c
- d, c, g, b
- b and a



# QUANTUM THEORY AND THE ATOM

**On what does the number of emitted electrons in the photoelectric effect depend?**

- Light frequency only
- Light intensity only
- The work function of the metal only
- The difference between the light frequency and the work function of the metal

**What happens when we increase the intensity of a light beam that does *not* liberate electrons from the surface of a metal?**

- The energy of the photons increases and electrons are emitted
- The number of incident photons increases but electrons are *not* emitted
- The number of emitted electrons increases
- The number of emitted electrons per second increase

**A monochromatic light of a single color is shined on a metal surface and releases electrons with zero kinetic energy.**

**What do you expect to happen if the *intensity* of this light is increased?**

- The number of emitted electrons increases and each has greater kinetic energy
- The number of emitted electrons increases but each has the same kinetic energy (= 0)
- The number of emitted electrons decreases and each has greater kinetic energy
- The number of emitted electrons remains the same and each has zero kinetic energy

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**Write the property demonstrated by each phenomenon or experiment:**

1. **Light diffraction:**  
→ *The wave nature of light.*
2. **Electron diffraction:**  
→ *The wave nature of matter.*
3. **Compton effect:**  
→ *The particle nature of light (or radiation).*
4. **Photoelectric effect:**  
→ *The particle nature of light (or radiation).*



# QUANTUM THEORY AND THE ATOM

16. **Photovoltaic Materials** Why is high-intensity, low-frequency light unable to eject electrons from a metal, whereas low-intensity, high-frequency light can?
17. **Frequency and Energy of Hot-Object Radiation** As the temperature of an object is increased, how does the frequency of peak intensity change? How does the total amount of radiated energy from the object change?
18. **Photoelectric and Compton Effects** Distinguish the photoelectric effect from the Compton effect.
19. **Solar Cells** What are solar cells? Describe how they function.
20. **Photoelectric Effect** Green light ( $\lambda = 532 \text{ nm}$ ) strikes an unknown metal, causing electrons to be ejected. The ejected electrons can be stopped by a potential of 1.44 V. What is the work function, in eV, of the metal?
21. **Energy of a Photon** What is the energy, in eV, of the photons of a 650-nm laser pointer?
22. **Compton Effect** An X-ray strikes a bone, collides with an electron, and scatters. How does the wavelength of the scattered X-ray compare to the wavelength of the incident X-ray?
23. **Photoelectric Effect** An X-ray is absorbed in a bone and releases an electron. The X-ray has a wavelength of about 0.02 nm. Find the electrons' energy, in eV. Assume the work function of bone is negligible compared to the X-ray's energy.
24. **Critical Thinking** Imagine that the collision of two billiard balls models the interaction of a photon and an electron during the Compton effect. Suppose the electron is replaced by a much more massive proton. Would this proton gain as much energy from the collision as the electron does? Would the photon lose as much energy as it does when it collides with the electron?



# QUANTUM THEORY AND THE ATOM

## 2-Matter Waves (De Broglie Waves)

- Electromagnetic waves have particle-like properties.
- De Broglie proposed that matter can also be described using wave properties.
- The De Broglie wavelength is equal to Planck's constant divided by the momentum of the object:

• تمتلك الموجات الكهرومغناطيسية خصائص تشبه خصائص الجسيمات .  
• اقترح دي برولي أن المادة يمكن أيضاً وصفها باستخدام خصائص موجية .

• يُعطى الطول الموجي لدي برولي بالعلاقة:  
حيث يساوي ثابت بلانك مقسوماً على كمية حركة (زخم) الجسم.

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

- As the speed of an object increases, its wavelength becomes shorter.
- Objects in our daily life do not show wave behavior because their wavelengths are extremely small and cannot be observed.

كلما زادت سرعة الجسم، أصبح طوله الموجي أقصر .

الأجسام في حياتنا اليومية لا تُظهر سلوكاً موجياً لأن أطوالها الموجية صغيرة جداً ولا يمكن ملاحظتها.

### Example

- A baseball with a mass of 0.145 kg is hit at a speed of 38 m/s. Use the De Broglie wavelength equation to calculate the wavelength of the baseball.



$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34} \text{ J}\cdot\text{s}}{(0.145 \text{ kg})(38 \text{ m/s})} = 1.2 \times 10^{-34} \text{ m}$$

The wavelength of everyday objects is extremely small, so it cannot be observed.



# QUANTUM THEORY AND THE ATOM

**DE BROGLIE WAVELENGTH** An electron is accelerated by a potential difference of 75 V. What is its de Broglie wavelength?

## 1 ANALYZE AND SKETCH THE PROBLEM

Include the positive and the negative plates in your drawing.

**Known**

$$\Delta V = 75 \text{ V}$$

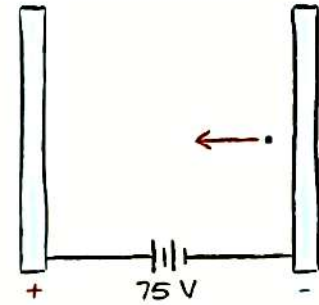
$$e = -1.602 \times 10^{-19} \text{ C}$$

$$m_e = 9.11 \times 10^{-31} \text{ kg}$$

$$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$$

**Unknown**

$$\lambda = ?$$



$$KE = \frac{1}{2} m v^2$$

$$v = \sqrt{\frac{2KE_{max}}{m}} = \sqrt{\frac{2 \times 75 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} = 5.13 \times 10^6 \text{ m/s}$$

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(5.13 \times 10^6)} = 1.4 \times 10^{-10} \text{ m} = 0.14 \text{ nm}$$

**A 7.0-kg bowling ball rolls with a speed of 8.5 m/s.**

- What is the De Broglie wavelength of the bowling ball?
- Why does the bowling ball not show noticeable wave behavior?

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{(7.0)(8.5)} = 1.11 \times 10^{-35} \text{ m}$$

**What accelerating potential difference is needed for an electron so that its wavelength becomes 0.125 nm?**

$$\lambda = \frac{h}{mv}$$

$$v = \frac{h}{m\lambda} = \frac{6.63 \times 10^{-34}}{(9.1 \times 10^{-31})(0.125 \times 10^{-9})} = 5.83 \times 10^6 \text{ m/s}$$

$$KE = \frac{1}{2} m v^2$$

$$KE = \frac{1}{2} (9.1 \times 10^{-31})(5.83 \times 10^6)^2 = 1.45 \times 10^{-17} \text{ J} = 96.6 \text{ eV}$$



# QUANTUM THEORY AND THE ATOM

Since the kinetic energy of the electron equals the electric potential energy:

$$\Delta V = 96.6 \text{ V}$$

De Broglie's theory provides a way to calculate the wavelength of all moving particles. Explain why wave behavior is not noticeable for the objects we use in daily life.

Because the De Broglie wavelength is extremely small, making it impossible to detect.

An alpha particle (a helium nucleus) has a mass of  $6.6 \times 10^{-27} \text{ kg}$  and moves with a speed of  $120 \text{ m/s}$ .

What is the De Broglie wavelength associated with this alpha particle?

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{(6.6 \times 10^{-27})(120)} = 8.4 \times 10^{-10} \text{ m} = 0.84 \text{ nm}$$

## Position and Momentum

### Heisenberg's Uncertainty Principle

It is impossible to measure both the position of an object and its momentum accurately at the same time because light has a dual wave-particle nature.

When we use high-energy photons to measure the position of a particle, the energy of the photon causes a large change in the particle's momentum.

Therefore, increasing accuracy in measuring position makes the uncertainty in momentum larger.

من المستحيل قياس موضع جسم وزخمه (كمية حركته) بدقة في نفس الوقت، لأن للضوء طبيعة مزدوجة (موجية وجسيمية).

عند استخدام فوتونات ذات طاقة عالية لقياس موضع جسيم، فإن طاقة الفوتون تُحدث تغييرًا كبيرًا في زخم الجسيم.

لذلك، كلما زادت دقة قياس الموضع، زادت عدم اليقين في قياس الزخم.



# QUANTUM THEORY AND THE ATOM

## What happens when a high-energy photon collides with an electron?

A collision between a high-energy photon and a particle causes a big change in the particle's momentum.

Measuring the electron's position requires a collision between the electron and the photon, which changes the momentum of both of them.

After the collision, the photon's wavelength becomes longer because it has lost energy.

يؤدي تصادم فوتون عالي الطاقة مع جسيم إلى تغيير كبير في زخم الجسيم.

يتطلب قياس موضع الإلكترون حدوث تصادم بين الإلكترون والفوتون، مما يؤدي إلى تغيير زخم كل منهما.

بعد التصادم، يصبح الطول الموجي للفوتون أطول لأنه فقد جزءًا من طاقته.

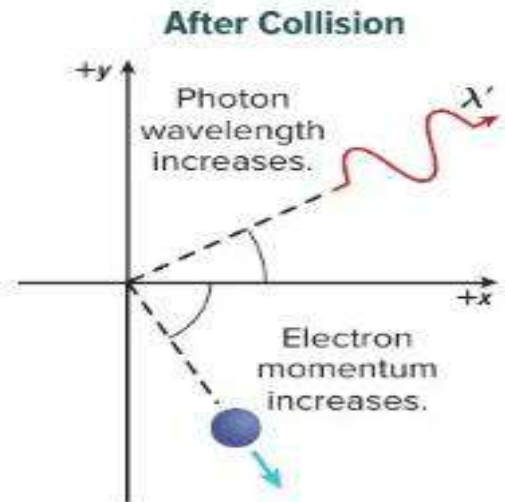
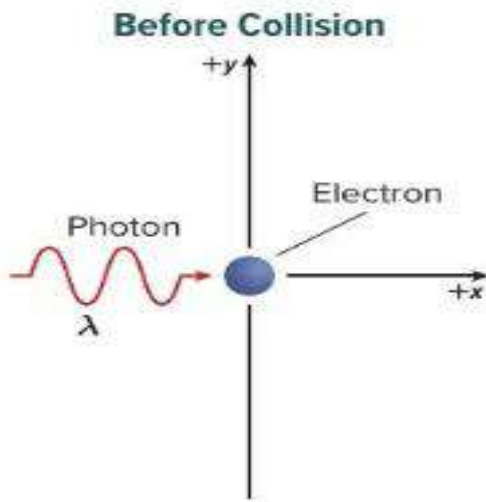
## Compare the photon's wavelength before and after the collision

After the collision, the photon's wavelength increases.

This increase in wavelength means the photon has lost part of its energy.

بعد التصادم، يزداد الطول الموجي للفوتون.

وهذه الزيادة في الطول الموجي تعني أن الفوتون قد فقد جزءًا من طاقته.



# QUANTUM THEORY AND THE ATOM

1. Photons are emitted from a helium–neon laser with a wavelength of 632.8 nm. What is the energy of each photon emitted by the laser (in joules)?

- A.  $3.135 \times 10^{-19}$  J
- B.  $8.231 \times 10^{-17}$  J
- C.  $2.546 \times 10^8$  J
- D.  $1.639 \times 10^{34}$  J

$$E_{eV} = \frac{1240}{\lambda_{nm}} = \frac{1240}{632.8} = 1.960 \text{ eV}$$
$$E = 1.960 \text{ eV} \times 1.6 \times 10^{-19} = 3.135 \times 10^{-19} \text{ J}$$

2. Light with an energy of 5.17 eV is incident on a photoelectric cell, as shown below. If the work function of the cell is 2.31 eV, what is the energy of the emitted photoelectrons?

- A. 0.00 eV
- B. 2.23 eV
- C. 2.86 eV
- D. 7.48 eV

$$KE_{max} = E - W$$
$$KE_{max} = 5.17 - 2.31 = 2.86 \text{ eV}$$
$$KE_{max} = \frac{1}{2} m v^2$$
$$v = \sqrt{\frac{2KE_{max}}{m}} = \sqrt{\frac{2 \times 2.86 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} = 1.00 \times 10^6 \text{ m/s}$$

3. If a photon has a frequency of  $1.14 \times 10^{15}$  Hz, what is the photon's energy?

- A.  $5.82 \times 10^{-49}$  J
- B.  $7.55 \times 10^{-19}$  J
- C.  $8.77 \times 10^{-19}$  J
- D.  $1.09 \times 10^{-12}$  J

$$E = hf = (6.63 \times 10^{-34})(1.14 \times 10^{15}) = 7.55 \times 10^{-19} \text{ J}$$

4. What physical quantity related to photons is represented by the symbol  $Z$  in the equation:

- Photon energy
- Photon wavelength
- Photon mass
- Photon momentum

$$Z = \frac{h}{\lambda}$$

5. What physical quantity related to photons is represented by the symbol  $Z$  in the equation:

- Photon energy
- Photon wavelength
- Photon mass
- Photon momentum

$$Z = \frac{1240}{\lambda_{nm}}$$



# QUANTUM THEORY AND THE ATOM

6. When a photon collides with a stationary electron, the photon scatters and the electron moves. Which phenomenon does the figure represent?

- Photoelectric effect
- Compton effect
- De Broglie waves
- Planck's quantum theory



7. When a photon collides with a stationary electron, the photon scatters and the electron moves. Which of the following statements is correct?

- The photon's wavelength decreases
- The photon's wavelength increases
- The photon's energy increases
- The photon's frequency increases



8. If the temperature of a body is doubled, by what factor does the emitted energy change?

- 2
- 4
- 8
- 16

The graph shows the relationship between the maximum kinetic energy of emitted electrons and the frequency of the incident radiation for three metals.

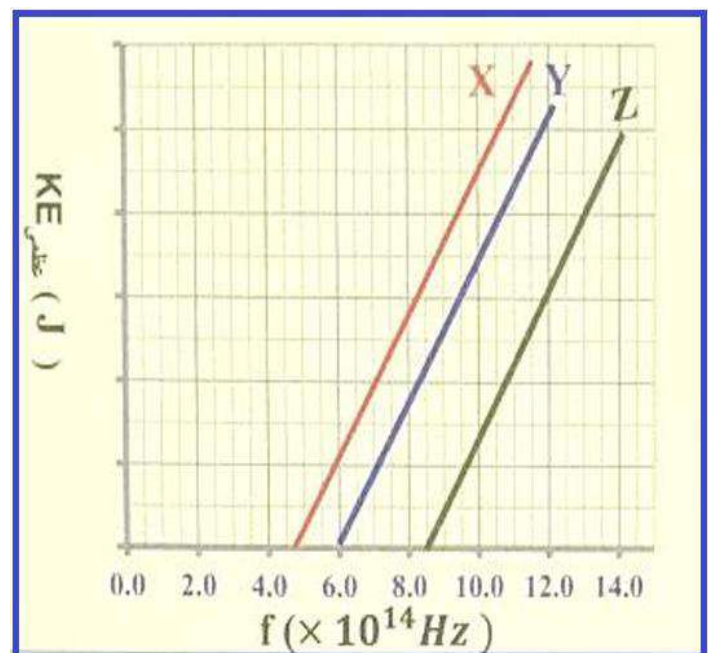
1 What does the slope of the graph for metal Y represent?

2 When light with wavelength:  $4.5 \times 10^{-7} \text{m}$

falls on the three metals, which metals emit electrons?

3 Calculate the stopping potential of the electrons emitted from metal Z when light of frequency:

$1.0 \times 10^{15} \text{Hz}$  falls on it



# QUANTUM THEORY AND THE ATOM

A photon is emitted from an excited hydrogen atom when an electron moves from an energy level of  $-0.85 \text{ eV}$  to  $-3.4 \text{ eV}$ .

Calculate the wavelength of the emitted photon.

Write the name of the property demonstrated by the phenomenon or experiment:

**Light quanta (photons):** the wave nature of light.

**Electron diffraction:** the wave nature of matter.

**Compton effect:** the particle nature of light or radiation.

**Photoelectric effect:** the particle nature of light or radiation.

---

What physical quantity related to photons is represented by the symbol  $Z$  in the

equation  $Z = \frac{hf}{c}$ ?

- Photon wavelength
- Photon energy
- Photon mass
- Photon momentum

---

Which of the following is correct when the temperature of a glowing lamp filament increases?

- The frequency of radiation at maximum energy increases.
- The frequency of radiation at maximum energy decreases.
- The wavelength of radiation at maximum energy increases.
- The wavelength of radiation at maximum energy does not change.

Two particles have equal mass.

The first moves with speed  $v$ , and the second moves with speed  $2v$ .

Which relation is correct for their de Broglie wavelengths?

- $\lambda_1 = \frac{1}{2} \lambda_2$
- $\lambda_1 = \frac{1}{4} \lambda_2$
- $\lambda_1 = \lambda_2$
- $\lambda_1 = 2\lambda_2$

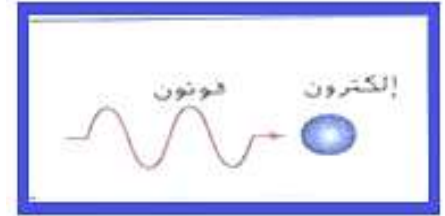


# QUANTUM THEORY AND THE ATOM

The figure shows an X-ray photon moving toward a stationary electron.  
When the photon collides with the electron:

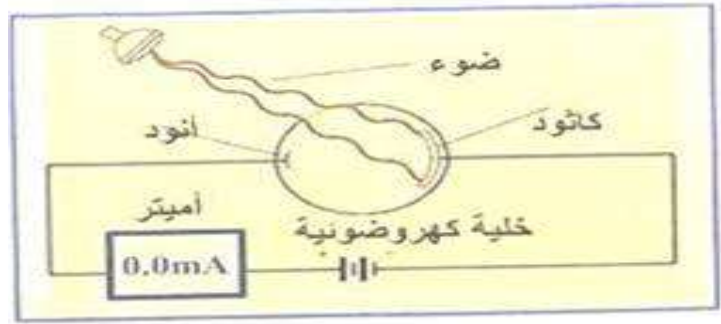
Which row is correct after the collision?

Photon	Electron
Its frequency decreases	Its momentum increases
Its frequency increases	Its momentum increases
Its wavelength increases	Its momentum does not change
Its wavelength decreases	Its momentum does not change



What happens to the ammeter reading in the photoelectric cell circuit when the intensity of light falling on the cathode increases?

- It increases then decreases.
- It increases then becomes constant.
- It changes alternately.
- It remains zero.



## PRACTICE Problems

## ADDITIONAL PRACTICE

Use  $E = 1240 \text{ eV}\cdot\text{nm}/\lambda$  to solve the following problems.

1. What is a photon's energy if the photon's wavelength is 515 nm?
2. A photon's energy is 2.03 eV. What is the photon's wavelength?
3. Rank the following photons from least to greatest energy.
  - a. 4.0 eV
  - b. 320 nm
  - c. 811 nm
  - d. 2.1 eV

4. **CHALLENGE** The diagram in **Figure 6** shows the visible light spectrum. What is the range of energies associated with photons in the visible light spectrum?

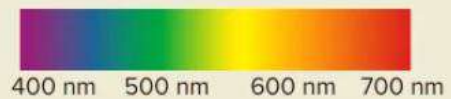


Figure 6



# QUANTUM THEORY AND THE ATOM

## عمالقة ميكانيكا الكم: من الموجات إلى الجسيمات

### عصر الموجات (الكلاسيكية)

جيمس كلارك ماكسويل (James Clerk Maxwell)

**الضوء كموجة كهرومغناطيسية**  
 تصفت نظرية ماكسويل في تفسير ظواهر التداخل، الحيود، والانعكاس. - معتمدة أن الضوء عبارة عن موجات وليس جسيمات.

### فجر التكميم والطبيعة المزدوجة (الكم)

ماكس بلانك (Max Planck)

**الطاقة كمقاة (Quantized)**  
 اقتوح طيفك أي الخارات غير فصرها على تغير طاقها يتخطى محطرين بل يوجد الطاقة في ذرم محددة تسمى "كمات".

**معادلة الطاقة الاقترانية**  
 $E = nhf$

طاقة اقتران الخيات لخطي بالعلقة  $E = hf$  حيث  $h$  هو ثابت بلانك  $6.63 \times 10^{-34}$  جول.ثانية

### الظاهرة الكهروضوئية (Photoelectric Effect)

**تحرير الإلكترونات بواسطة الضوء**  
 تترسب الإلكترونات من اسطح الفلزات عند تعرضها للإشعاع ذو تردد مناسب للتردد الحدية  $f_0$ .

**الطاقة تعتمد على التردد لا الشدة**  
 على محطد الشدة والاعتماد على التردد. طاقة الإلكترونات المنطلقة تزداد بزيادة تردد الضوء، وفقط تردد الشدة فحسب من عدد الإلكترونات إذا كان  $f > f_0$ .

**تطبيقات الخلية الكهروضوئية**  
 تستخدم في الخلايا الشمسية لتحويل الضوء إلى كهرباء، وفي الأبواب الأوتوماتيكية باستدأ أشعة تحت الحمراء.

### زخم الفوتون

أرتور كومبتون (Arthur Compton)

**تصادم الفوتونات والإلكترونات**  
 عند اصطدام فوتون بشحنة موجبة (إلكترون) يفقد الفوتون جزءاً من طاقته، مما يولد طول موجي (λ) يتناما بأكسب الإلكترون طاقة حركية.

**إثبات الطبيعة الجسيمية**  
 أثبات تجربة كومبتون أن الفوتونات تمتلك زخماً (p = h/λ) وتكسب الجسم مادية اصطدام وتتوزع الطاقة والزخم.

### الطبيعة المزدوجة

لويس دي برولي (Louis de Broglie)

فيرنر هايزنبرج (Erwin Schrödinger)

$\lambda = h/mv$

موجات المادة لدي برولي اقترح دي برولي أن الجسيمات العادية لها سلوك موجي، وطولها الموجي  $\lambda = h/mv$ ، حيث  $h$  هو ثابت بلانك،  $m$  كتلة الجسيم، و  $v$  سرعته.

مبدأ عدم اليقين لجويزنبرج من المستحيل قياس موضع الجسم وزخمه بدقة في نفس الوقت بسبب الطبيعة المزدوجة (موجة - جسيم).

### حدود النظرية وفشلها

عجزت الفيزياء الكلاسيكية عن تفسير طيف البعث الأجسام الساخنة الإشعاع الجسم الأسود، وامتنع الإشعاع الكهروضوئية.

**مقارنة تأثير درجة الحرارة على إشعاع الجسم الأسود**

المصير	عند زيادة درجة الحرارة
الطول الموجي القم (λ)	يقل (ينتجه نحو البنفسجي)
القدرة المنبعثة (Power)	تزداد (تناسب مع $T^4$ )
شدة الإشعاع القصوى	تزداد
تغير اللون المرئي	أحمر - برتقالي - أصفر - أخضر - أزرق

## Pioneers of the Atom: The Evolution of Quantum Theory

### The Classical Wave Theory vs. The Quantum Break

**Maxwell's Wave Theory (Classical)**  
 Defined light as electromagnetic waves, successfully explaining interference, diffraction, and polarization, but failing to explain the photoelectric effect.

### The Dual Nature of Light and Matter

**The Compton Effect (Photons as Particles)**  
 Arthur Compton proved photons have momentum ( $p = h/\lambda$ ) by showing they lose energy and increase in wavelength when colliding with electrons.

**De Broglie's Matter Waves**  
 Louis de Broglie flipped the script, proposing that if light can be a particle, then particles (like electrons) can behave like waves with a wavelength of  $\lambda = h/mv$ .

### The Limits of Measurement

**Heisenberg's Uncertainty Principle**  
 States it is impossible to measure both a particle's position and momentum accurately at the same time.

**Planck's Quantization (The Turning Point)**  
 Discovered that atoms do not change energy continuously; instead, energy is "quantized" in discrete packets (quanta).

$E = nhf$

**Real-World Duality**  
 While a baseball has a De Broglie wavelength, it is too small to observe; however, for subatomic particles, this wave nature is critical.

**The "Observer" Effect**  
 Using a high-energy photon to measure an electron's position inevitably changes its momentum, creating inherent uncertainty.

**The Photoelectric Effect**  
 Einstein proposed that light exists as "photons," where energy depends on frequency ( $E = hf$ ), proving that intensity alone cannot release electrons from metal.

$E = hf$

Scientist	Key Discovery	Impact on Physics
Maxwell	Electromagnetic Wave Theory	Established the classical wave nature of light
Planck	Energy Quantization	Birth of Quantum Theory; energy is discrete, continuous
Einstein	Photoelectric Effect	Defined the "Photon" and explained particle behavior of collisions
Compton	Photon Momentum	Proved photons behave like wave-winned in collisions
De Broglie	Particle-Wave Duality	Proved that matter has wave-like and the properties
Heisenberg	Uncertainty Principle	Showed the limits of measurement at an atomic scale

