College Physics

Lect. # 1

For

Engineering Students

Dr. Eng.

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Cairo 2014

- **Lect. : 1**
- **Chapter: 1**

"Oscillation Motion"

- * **Contents**:

1- Angular Quantities

2- Basic Concepts

3- Simple Harmonic Motion (SHM)

4- SHM Parameters

تعريف بالمادة

Chapter	Title	No. of Lectures
1	Oscillatory Motion	2
2	Wave Motion	2
3	Sound Waves	2
4	Superposition and Standing Waves	2
5	Optics Waves	1
6	Diffraction and Polarization	1
7	Quantum Physics	2

Subject	Mark
Mid Term	25
Lab	15
Section	10
Final	75
Total	**125**

تعريف بأستاذ المادة .. أ.د/ ممدوح مصطفى

* مؤهلات علمية:

1. بكالوريوس هندسة كهربية – جامعة عين شمس
2. ماجستير هندسة كهربية – جامعة عين شمس
3. دكتوراه هندسة كهربية – جامعة عين شمس
4. أستاذ مشارك – تخصص قوى و آلات كهربية
5. أستاذ دكتور – تخصص قياسات كهربية
6. ليسانس آداب إنجليزي – تخصص ترجمة - جامعة القاهرة
7. ليسانس أصول دين – تفسير وعلوم قرآن – جامعة الأزهر
8. دبلوم دراسات عليا – ثقافة إسلامية – وزارة الأوقاف
9. إجازة قراءة حفص – معهد قراءات القرآن الكريم – الأزهر الشريف

10- دبلوم دراسات عليا في تدريس اللغة العربية للناطقين بغيرها – كلية دار العلوم

* مهام وظيفية حالية وسابقة:

1. أستاذ الفيزياء الهندسية - كلية الهندسة – جامعة حلوان
2. أستاذ امادة لاكترونيات وهندسة الصوت بالمعهد العالي للسينما
3. أستاذ مادة أجهزة القياس بالأكاديمية العربية البحرية
4. أستاذ مادة ضبط الجودة بالمعهد العالي للهندسة بأكتوبر
5. رئيس شعبة مترولوجيا الهندسة الكهربية بوزارة البحث العلمي
6. مقيم فني معتمد لمختبرات المعايرة والقياسات والاختبارات الكهربية
7. أستاذ مشارك هندسة كهربية – جامعة حائل بالسعودية
8. مقيم رئيسي معتمد لجائزة الملك عبد العزيز للجودة بالرياض

* **Lect. : 1**

* **Chapter: 1**

Oscillatory Motion الحركة التذبذبية

* **Contents:**

1- Angular Quantities الكميات الزاوية

2- Basic Concepts مفاهيم أساسية للحركة

3- Simple Harmonic Motion (SHM) الحركة التوافقية البسيطة

4- SHM Parameters عناصر ومفردات الحركة

(x – v – a – K.E – P.E – U – F – vector diagram)

(1) Angular Quantities

Based on the uniform circular motion, many new parameters have been located to describe this type of motion, such as angular displacement, angular velocity, angular acceleration and kinematics angular equations.

i. Angular Displacement (θ) الإزاحة الزاوية

It is usually expressed in degrees or in radians (or in revolutions). One radian is the angle subtended at the center of a circle by an arc equal in length to the radius

يمكن تعريف الراديان بأنه قيمة الزاوية المركزية التي يتساوى عندها طول القوس مع نصف قطر الدائرة .

Since circumference = $2\pi r$, the angular displacement in one revolution is 2π r

Where 1 revolution = $360^o = 2\pi$ r,
1 radian (زاوية نصف قطرية) = $360/2\pi$ or **1 radian = 57.3^o**

Note:

- **radian is a measure of an angle**
- **radian = (arc length/radius length) and is given by:**

$$\theta = \frac{S}{r}$$

ii. Angular Velocity (ω) السرعة الزاوية

It is expressed in radian/sec (or revolutions/min, rpm). If a body describes an angle (θ) radians in (t) sec, its average angular speed (ω) in radians per second (rad/sec) is:

$$\omega = \frac{\Delta\theta}{\Delta t}$$

The angular velocity can be also given by:

$$\omega = 2\pi f$$

Where f is the frequency in rev. /sec (Hz)

iii. Angular Acceleration (α), (rad. / sec^2) العجلة الزاوية

If the angular velocity of a body changes uniformly from (ω_i) to (ω_f) in t sec, the angular acceleration (a) is given in:

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_f - \omega_i}{\Delta t}$$

It is expressed in (radian per sec) per sec (rad. / sec^2)

iv. Relation between Angular and Linear Quantities

$$\theta = \frac{s}{r} ..(rad)$$

$$\omega = \frac{V}{r} ..(rad/s)$$

$$\alpha = \frac{a}{r} ..(rad/s^2)$$

Where:

- S = length of arc in (m)
- r = radius of circle in (m)
- V = linear speed in (m/s)
- a = linear acceleration in (m/s^2)

Notes

You can also convert the linear laws of the circular motion into the angular form as following:

The Centripetal Acceleration α

العجلة المركزية في الحركة الدائرية

$$\alpha = \frac{V^2}{r} = \frac{(\omega . r)^2}{r} = \omega^2 . r$$

The Centripetal Force F_c

القوة المركزية في الحركة الدائرية

$$F_C = m\frac{V^2}{r} = m\omega^2 . r$$

Units and Conversions وحدات وتحويلات

- Radian = 57.3 degrees
- Radian = Revolution / 2 π
- Ft = 12 inch = 30.48 cm
- Inch = 2.54 cm
- Mile = 1.61 km
- 1 mile/hr = 0.447 m/s
- rpm = (π / 30) rad/s
- rps = (2 π) rad/s
- Pound (lb) = 0.454 kg.
- Gravity, g = 9.8m/s^2 = 32 ft/s^2

Ex 1: A 36 cm pendulum swings through a 9 cm arc. Find the angular displacement (θ) in radians and in degrees.

$$\theta = \frac{S}{r} = \frac{9}{36} = 0.25 radian$$

$$\theta = 0.25 * 57.3^o = 14.3^o$$

Ex 2: Convert:

* 5 radian to revolution

* 300 revolution to radian

* 720 rpm to rad/s

* 5 rad = 5 / 2 π = 2.5/ π rev.

* 300 rev. = 300 * 2 π = 600 π rad.

* 720 rpm = 720 * π / 30 = 24 π rad/s.

(2) Basic Concepts مفاهيم أساسية للحركة

The following are good examples for this type of motion:

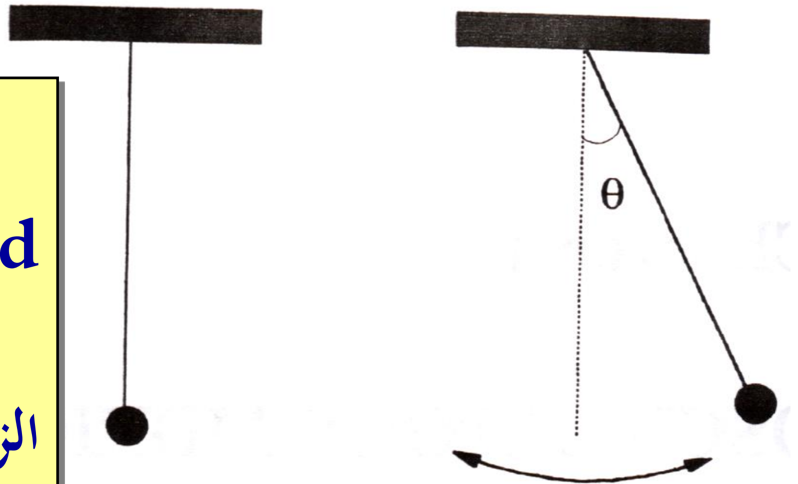
- **Vibration of a quartz crystal in a watch** اهتزاز بلورة الكوارتز في بعض الساعات
- **Swinging pendulum** البندول المتأرجح
- **Sound vibration of the clarinets** سارينة الصوت
- **Back-forth motion of the piston in the car engine.** حركة المكابس في محركات السيارات
- **Motion of mass attached to a spring ….. etc.** حركة كتلة مثبتة في زنبرك

- **You can clearly note that, all these examples repeat themselves and have a repetitive or cyclic motion. In this chapter, we develop some descriptions of oscillatory motion that applies to many engineering systems.**

The periodical Time (T)

It is the time (in second) required for one oscillation

الزمن الدوري هو الزمن الذي تستغرقه الذبذبة الكاملة



The frequency (f)

It is the number of vibration made per second in Hz.

التردد هو عدد الاهتزازات الكاملة في الثانية الواحدة ويقدر بوحدة الهيرتز

$(T = 1/ f)$

The Displacement (x)

It is the distance (in m) of the vibrating body at any instant from its normal position of rest.

الإزاحة في الحركة الاهتزازية هي المسافة بين موضع الجسم المهتز في لحظة معينة وبين موضع سكونه الأصلي

The Amplitude (A)

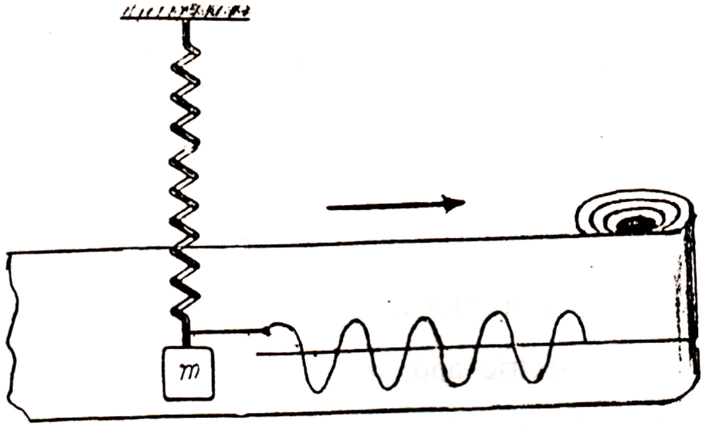
It is the maximum displacement (in m) made by the vibrating body in any direction.

سعة الاهتزاة هي أقصى إزاحة يصنعها الجسم المهتز بعيدا عن موضع سكونه

(3) Simple Harmonic Motion (SHM)

Mechanical oscillation can be studied with the aid of block-spring system as shown in the figure. The motion of mass (m) is recorded on a strip of paper that moves at a constant speed. We can find that the motion is represented by a sinusoidal wave.

i. Displacement (x) of SHM

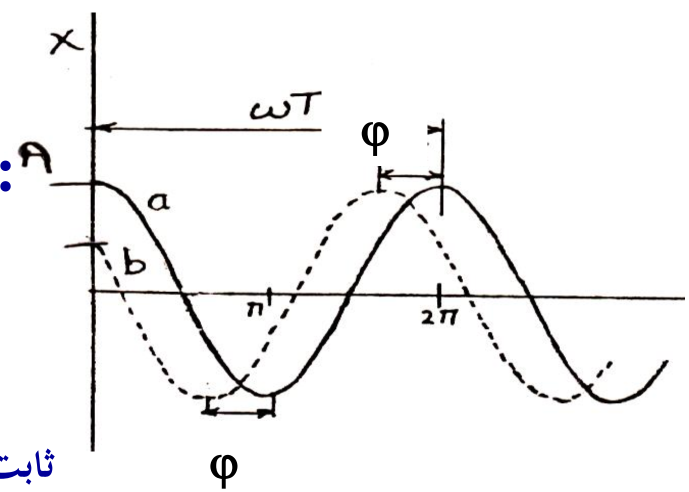


$$X = A.Cos\,\omega t$$

<u>Where:</u>

- **x = A at (t = 0)**
- **A: the amplitude of the motion in (m).**
- **ω: the angular frequency (2π f) in rad/s.**

<u>But in general, we can write the formula as</u>:



$$X = A.Cos(\omega t + \varphi)$$

- **(ωt + φ) is the phase angle زاوية الطور**
- **φ is the initial phase (or the phase constant) ثابت الطور**

Notes of SHM:

1) **The amplitude A is constant and doesn't depend on time**

لا تعتمد سعة الاهتزازة في الحركة التذبذبية على زمن الحركة بل تعتمد على قوة مصدر الذبذبة

2) **The restoring force acting on the spring is always proportional to its displacement from the normal position of rest and in a direction opposite to the displacement, i.e. toward the normal position of rest**

قوة الاسترداد التي تنشأ داخل الزنبرك تعتمد طرديا على مقدار الازاحة الحادثة فيه بفعل الاهتزاز ويكون اتجاهها عكس اتجاه الإزاحة الحادثة

3) **The frequency is independent on the amplitude.**

لايعتمد تردد الحركة المهتزة على سعة الاهتزازة بل يعتمد على الطريقة التي يهتز بها المصدر نفسه

ii. Velocity (V)of SHM

$$V = \frac{dX}{dt} = \overset{o}{X}$$

$$V = \overset{o}{X} = -\omega A.Sin(\omega t + \varphi)$$

iii. Acceleration (a)of SHM

$$a = \frac{d^2X}{dt^2} = \overset{oo}{X}$$

$$a = \overset{oo}{X} = -\omega^2 A.Cos(\omega t + \varphi)$$

Using the relations: $Cos(\omega t+\varphi)=\dfrac{X}{A}$ **and** $Sin(\omega t+\varphi)=\sqrt{1-Cos^2(\omega t+\varphi)}$ **to prove that:**

$$V=\overset{o}{X}=-\omega\sqrt{A^2-X^2}$$

$$a=\overset{oo}{X}=-\omega^2 X$$

or $$\overset{oo}{X}+\omega^2 X=0$$

According to these equations, at X = 0 (when the mass passes its equilibrium position), the maximum velocity V_{max} is given by: $V_{max}=\omega.A$

However, the maximum acceleration will occur when X = A then become:

$$a_{max}=\omega^2.A$$

iv. Kinetic Energy (K.E) of SHM

A mass (m) which makes SHM, has a velocity: $V=\omega\sqrt{A^2-X^2}$

its kinetic energy at the time t is given by: K.E = 0.5 m V^2

$$K.E=\frac{1}{2}m\omega^2(A^2-X^2)$$

and @ x = 0

$$K.E_{max}=\frac{1}{2}m\omega^2A^2=\frac{1}{2}KA^2$$

Where K is a constant called the force constant $k=m\omega^2$

v. Potential Energy (P.E) of SHM

The potential energy of the mass m at its equilibrium position is zero since there is no forces acting on it. As the mass makes a displacement x, a force F given by: $F = m\,a = -\,m\,\omega^2\,x$

This force will act on the body so that it acquires a potential energy P.E given by:

$$P.E = -\int_0^X F.dX = -\int_0^X -(m\omega^2 X)dX$$

$$P.E = \frac{1}{2}m\omega^2 X^2$$

Note that:

1- as the displacement x from the equilibrium position increases, the kinetic energy decreases, while the potential energy increases

***2*- when x reaches a maximum value x = A, the potential energy reaches to its maximum value $P.E_{max}$ where:**

$$P.E_{max} = \frac{1}{2}m\omega^2 A^2 = \frac{1}{2}KA^2$$

Thus: $K.E_{max} = P.E_{max}$

vi. Mechanical Energy (U) of SHM

The total mechanical energy U of oscillator is given by:

$$U = K.E + P.E$$

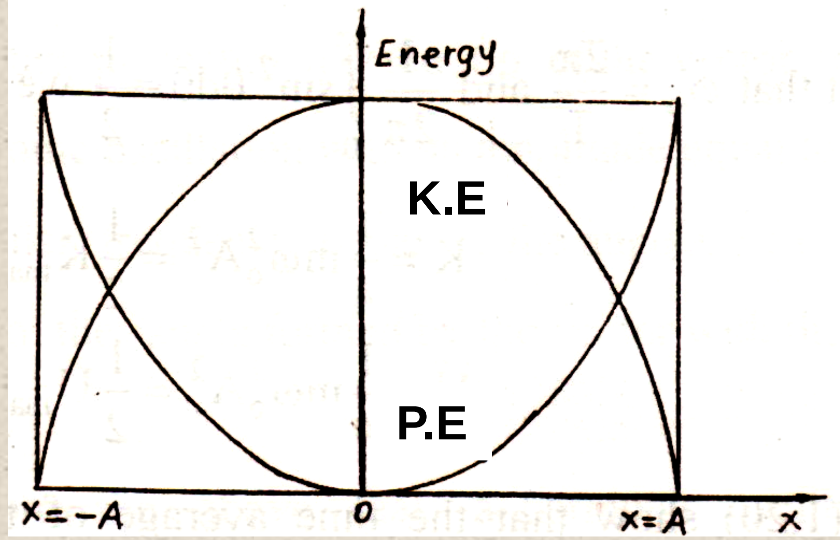
$$U = \frac{1}{2}m\omega^2(A^2 - X^2) + \frac{1}{2}m\omega^2 X^2$$

$$U = \frac{1}{2}m\omega^2 A^2 = \frac{1}{2}KA^2$$

Then

$$U = K.E_{max} = P.E_{max}$$

The variation of the kinetic and potential energies as a function of X, for a harmonic oscillator is illustrated by the graph:



It was found that, all SHMs are characterized by a parabolic curve where the potential energy is proportional to the square of the displacement.

Ex 3:

1. A 4 lb steel block vibrates in SHM with amplitude A =9 inch and period T=3 Sec. Find:

- The frequency
- Max. speed and the speed at displacement x = 6 inch
- Max. acceleration and at displacement x = 6 inch
- Max. restoring force acting on it and at x = 5 inch
- Max. K.E
- Max. P.E
- Total energy of the vibrating block at any position U

Sol:

- Frequency υ = 1/T = 0.33 Hz

- $V_{max} = \omega.A$ = 2 π υ A = 1.57 ft/sec.

  At x = 6 inch, $V = \omega\sqrt{A^2 - X^2}$ = 1.17 ft/sec.

- $a_{max} = \omega^2.A$ = 3.29 ft/sec^2 toward center of path

  At x = 6 inch, $a = \omega^2.X$ = 2.19 ft/s

- At X=A= 9inch,

  $F = m.a_{max}$ = (4/32 slug) x 3.29 ft/s^2 = 0.41 lb

where the restoring force is proportional to displacement x, and F = 0.41 lb at x = 9 inch, restoring force at x = 5 inch is given by:
F = 5/9 x 0.41 = 0.32 lb.

Note:

- 1 slug = 32 lb = 14.59 kg.
- 1 kg. Weight = 2.205 lb = 9.8 Newton

- $K.E_{max} = 0.5\ m\ V^2_{max}$ (at x = 0)
  = 0.5 (4/32 slug) (1.57 ft/s^2) = 0.154 ft-lb

- $P.E_{max} = K.E_{max}$ = 0.154 ft-lb (at ends of path)

- Total energy U at any position:
  $U = P.E_{max} = K.E_{max}$ = 0.154 ft-lb

Sheet 1

1. **A spring makes 12 vibrations in 3 seconds. Find the period T and frequency υ of the vibration.** **(4 Hz)**
2. **A 5 gm body is suspended by a long and light spiral spring. An added force of 2 N stretches the spring 4 cm. Find: * The force constant** **(50 N/m)**
3. **A body oscillates with SHM along the x-axis. Its displacement varies with time according to equation:**

$$X = 0.04 Cos(\pi.t + \pi / 4)$$

where t in sec and the angles in radian. Find:

a. **The amplitude, frequency, the period of this motion**
b. **Find the velocity and acceleration of the body as a function in time t**
c. **Calculate the position, velocity and acceleration of the body at time = 1 sec.**
d. **Calculate the max speed and max acceleration of that body**
e. **Find the displacement of the body between t = 0 and t = 1 s**
f. **Find the phase angle at t = 2 s**

(4 m - 0.5 Hz - 2 sec - - 2.83 m - 8.89 m/s - 27.9 m/sec^2 - 4 π m/s - 4 π^2 m/s^2 - - 5.66 m - 9π/4 rad)

<u>4. Define the following:</u>
*** The period**
*** The frequency**
*** The displacement**
*** The simple harmonic motion**

5. A mass of 1 kg vibrates up and down along a straight line, 20 cm long, in SHM with a period of 4 sec. Find:

*** The amplitude**

*** the speed and acceleration at the midpoint of its path**

*** the speed and acceleration at the upper end of its path * the speed and acceleration when its displacement is 4 cm * the restoring force at the midpoint of its path**

*** the restoring force at the lower end of its path**

*** the restoring force at displacement of 8 cm below the center of its path.**

Answers:

(10 cm – 5π cm/sec – 0 cm/sec^2 – 0 cm/sec – 2.5π^2 cm/sec – 14.4 cm/sec - π^2 cm/sec^2 – 0 – 0.025 π^2 N – 0.02 π^2 N)

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6. A 0.7 kg mass connected to a light spring of force constant 30 N/m oscillates on a horizontal friction less track, find:

a. the total energy of the system

b. the max. speed of the mass if the amplitude of the motion is 3 cm.

c. the velocity when the displacement is 2 cm

d. the kinetic and potential energies of the system at displacement = 2 cm

Answers: (0.0135 J – 0.196 m/s - 0.146 m/s - 0.0075 J - 0.006 J)

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7. The initial phase of harmonic vibration = 0. Its velocity = 3 cm/s at displacement = 2.4 cm. While, its velocity = 2 cm/s at displacement = 2.8 cm. Find the amplitude and the perodical time of this vibration. (0.031 m – 4.1 sec)

8. a 200 gm mass is attached to a spring of force constant K=5.6 N/m and set into oscillation with amplitude A = 25 cm. Find:

*** Frequency *Period * Max. Speed * Max. Force**

Ans: (0.842 Hz – 1.187 Sec - 1.323 m/s - 1.4 N)

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9. A mass m of 800 gm is attached to a spring with a force constant K= 80 N/m. The mass is pulled a distance x = 10 cm from its equilibrium position at x = 0 on a frictionless surface and released from rest at t = 0. Evaluate:

*** The angular frequency and the period**

*** The amplitude and the initial phase constant, φ.**

*** The max. speed and max. acceleration of the mass**

*** The equation of the displacement function X (t).**

Ans: (10 rad/s – 0.628 sec. – 0.1 m – 0^o - 1 m/s - 10 m/s^2 – X (t) = 0.1 Cos (10 t + 0^o))

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10. A pendulum makes 90 vibrations in 1 minute. Find the period and the frequency

(0.7 sec. - 1.5 Hz)

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11. <u>Convert:</u>

*** 50 revolutions to radian**

*** 48 π radians to revolutions**

*** 10 radian to degrees**

- **1500 revolution per minute (rpm) to rad/s**

(100 π – 24 rev. – 573^o – 50 π rad/s)

12. A ball of mass 0.5 kg is attached to the end of a wire whose length is 150 cm. The ball is whirled in a horizontal circle as in Fig. 5. What is the maximum tension can the wire response to provide the ball with a maximum speed of 5 m/s ? (8.33 N)

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13. The angular speed of a disk decreases uniformly from 12 to 4 rad/s in 16 sec. Compute the angular acceleration and the number of revolutions made in this time.

(-0.5 rad/s - 64/π rev.)

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14. What is the max speed at which an automobile can round a curve of 80 ft radius on a level road if the coefficient of friction between the tires and the road is 0.3 ?

(27.7 ft/sec)

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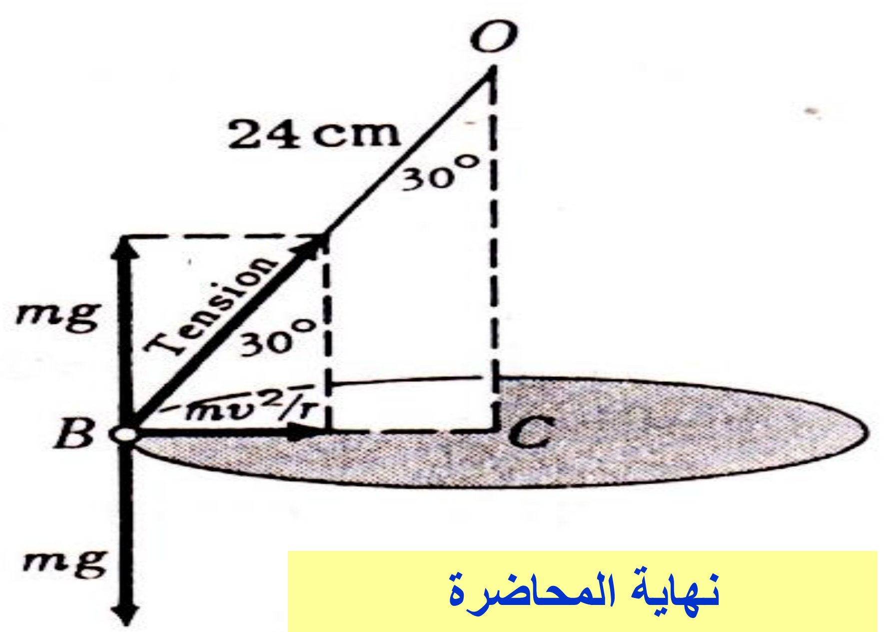
15. A ball at point B is fastened to one end of a string 24 cm long, and the other end is attached to a fixed point O. The ball describes a horizontal circle of radius CB about a center vertically under O. Find the speed of the ball in its circular path if the string makes an angle of 30^o with the vertical as shown in the Figure. (0.824 m/s)



نهاية المحاضرة