I'm not a bot

The air outside an IB exam room after the final paper feels different. Its a potent mix of exhaustion, relief, Certain objects move in a way that is characteristically rhythmic and repeating, without resulting in any net displacement. These objects move back and forth around a fixed position until friction or air resistance causes the motion to stop, or the moving object is given a fresh "dose" of external force.Examples include a child on a swing, a bungee jumper bouncing up and down, a spring pulled downward by a gravity, the pendulum of a clock, and the bored toddler's game of holding a ruler in one hand, pulling the top to one side, and releasing it so that the ruler goes "boing-boing-boing" rapidly back and forth before stopping in the upright position.Motion that occurs in predictable cycles is called periodic motion and includes a special subtype called **simple harmonic motion,** or SHM. Simple harmonic motion is a special kind of periodic motion where the restoring force depends directly on the displacement of the object and works in the opposite direction of it. Put another way, the restoring force grows in proportion to increasing distance, meaning that the farther a system gets from its equilibrium position, the harder it appears to fight to restore it.For example, when you pull down on a spring suspended vertically from above, this force displaces (stretches) the spring by a particular amount x; when you release the spring, the force arising from the spring's mechanical characteristics pulls the spring back in the opposite direction toward where it began.It may even return to a more-compressed state than the one in which it started, bounce outward again and go back and forth several times until stopping in the original resting position.The equilibrium point or position is that in which the net force is zero, so no acceleration is occurring then. (This is also when kinetic energy is maximized.)At maximum displacement, the maximum acceleration is achieved. (This is also when potential energy is maximized.)A graph of this displacement over time would trace out a sinusoidal curve of decreasing amplitude. Hooke's Law, or **F = **k**x,** can be used to describe simple harmonic motion for the examples here. The proportionality constant k, called the spring constant, depends on the specifics of the system being tested. Look online for making your own spring for an explanation of Hooke's law.Note that the restoring force is always in the opposite direction of the displacement x, explaining the negative sign in front of k. For an object hanging from a string, the restoring force from tension would be equal to the vertical component of the force of gravity:\(T = kx = mg\cos{\theta}\)At any point along the trajectory, this force can be found with the basic identities of trigonometry. The time period T required for one complete oscillation of a mass on a spring is given by:\(T=2\pi \sqrt{\frac{m}{k}}\)Similarly, the frequency f, or number of oscillations per unit time (usually per second, even if a decimal number), is given by the reciprocal of this expression, which is:\(f=\frac{1}{2\pi}\sqrt{\frac{k}{m}}\)Thus the period and frequency depend on the mass of the object as well as the constant k. It can be shown that the value of k for a classic simple pendulum, in which a mass m is suspended from a string of length L under the influence of gravity is mg/L , where g = 9.8 m/s2.What is the period of a pendulum 10 m long suspending a mass of 100,000 kg?With the substitution k = mg/L, the expression for T from above becomes:\(T=2\pi \sqrt{\frac{L}{g}}\)Where L = 10. Thus the period T is 6.35 s and does not depend on mass, which cancels out of the equation. (Of course, a very strong string would be required to withstand the tension in this pendulum!) Beck, Kevin. "Simple Harmonic Motion: Definition & Equations (W/ Diagrams & Examples)" sciencing.com, . 28 December 2020. APA Beck, Kevin. (2020, December 28). Simple Harmonic Motion: Definition & Equations (W/ Diagrams & Examples). sciencing.com. Retrieved from Chicago Beck, Kevin. Simple Harmonic Motion: Definition & Equations (W/ Diagrams & Examples) last modified March 24, 2022. Explore the fundamentals of Simple Harmonic Motion (SHM), its principles, equations, and real-world applications in physics and engineering.Understanding Simple Harmonic Motion (SHM)Simple Harmonic Motion (SHM) is a type of periodic motion or oscillation motion where the restoring force is directly proportional to the displacement and acts in the direction opposite to that of displacement. SHM is fundamental to the study of waves, sound, and other vibratory phenomena in physics.Basic Principles of SHMThe most classical example of SHM is the motion of a mass attached to a spring. When displaced from its equilibrium position, the mass experiences a restoring force F which is proportional to the displacement x, according to Hookes Law: F = -kx. Here, k is the spring constant, and x is the displacement. The negative sign indicates that the force acts in the direction opposite to the displacement.Equations of Motion in SHMThe motion of a simple harmonic oscillator can be described by the following differential equation:\[\frac{d^2x}{dt^2} + \omega^2x = 0 \]where \(\omega\) (omega) is the angular frequency of the motion. This differential equation has solutions that can be represented as:\[x(t) = A \cos(\omega t + \phi) \]Here, A is the amplitude of the motion, \(\omega t + \phi\) is the phase, and \(\phi\) is the phase constant. The velocity and acceleration in SHM can also be described using similar sinusoidal functions.Energy in SHMIn SHM, energy oscillates between kinetic and potential forms. The total mechanical energy E in SHM is constant and is given by:\[E = \frac{1}{2} kA^2 \]where A is the amplitude. At maximum displacement, the energy is all potential, and at the equilibrium position, it is all kinetic.Analysis of SHMSHM provides an idealized model for understanding vibrational systems. Real-world systems often deviate from perfect SHM due to factors like damping and external forces. However, SHM is crucial for understanding the fundamental concepts in wave motion, resonant systems, and other areas of physics.Further analysis involves exploring the effects of damping, forced vibrations, and resonance in systems exhibiting SHM.Damping and Forced Vibrations in SHMIn real-world scenarios, SHM is often influenced by non-ideal factors such as damping and external forces. Damping is a force that opposes the motion and reduces the amplitude over time. Its often proportional to the velocity and can be represented as:\[F_d = -b\frac{dx}{dt} \]where b is the damping coefficient. In the presence of damping, the system loses energy, leading to a gradual decrease in amplitude.Resonance in SHMResonance occurs when an external force applied to a system matches its natural frequency, resulting in a significant increase in amplitude. The resonance phenomenon is crucial in many applications, including musical instruments, bridges, and building design. Its crucial to understand and control resonance in engineering to avoid catastrophic failures.Applications of SHMSHM finds applications in various fields. In engineering, its used in the design of structures and machinery parts that experience oscillations. In electronics, oscillators that use SHM principles are fundamental in radios, clocks, and computers. In quantum mechanics, the harmonic oscillator model helps understand atomic and molecular vibrations.ConclusionSimple Harmonic Motion is a cornerstone concept in physics, providing a foundation for understanding oscillatory motion and waves. Its principles are not only fundamental in theoretical physics but also immensely practical in various engineering and scientific applications. From the basic understanding of springs and pendulums to the intricate design of electronic circuits and structural engineering, SHM continues to be a key concept, enriching our understanding of the natural and technological world. Its simplicity in form yet complexity in application makes it a fascinating and essential area of study in physics and engineering.You need to enable JavaScript to access Isaac Physics. Long ago, in the early 1600s, a curious scientist named Galileo Galilei made an unusual observation inside a large cathedral in Italy. As he sat watching a chandelier swinging gently from the ceiling, he noticed something fascinating the time it took for the chandelier to swing back and forth remained nearly the same, even as the swing became smaller. This caught his attention. Using nothing more than his own pulse to measure time, Galileo began to understand that this regular, repetitive motion had a pattern. Though he didnt yet call it simple harmonic motion, Galileo had stumbled upon one of the most important principles in physics periodic motion. Galileos interest didnt stop there. He experimented further with pendulums and found that for small swings, the time period depends only on the length of the pendulum and not on how far it swings. This idea became the foundation for using pendulums in clocks, bringing more accuracy to timekeeping than ever before. For the first time in history, scientists were beginning to measure time using natures rhythm. A few decades later, another brilliant mind, Robert Hooke, entered the scene. He was fascinated by springs and elasticity. In 1676, Hooke discovered that the force needed to stretch or compress a spring is directly proportional to the displacement. He summarized this idea with a simple but powerful equation: F = -kx This was called Hookes Law, and it introduced the concept of a restoring force a force that always pulls an object back toward its original position. Though Hooke was not directly talking about SHM, his discovery laid the mechanical groundwork for it. The idea that a system could continuously be pulled back toward equilibrium set the stage for understanding oscillations more deeply. Then came Isaac Newton, the father of classical physics. In his monumental work Principia Mathematica (published in 1687), Newton provided the laws of motion and applied them to various physical systems. He used calculus to explain how objects move and accelerate. When Newton looked at systems like pendulums and springs, he connected the ideas of force and acceleration. He showed mathematically that when a particle is pulled back by a force proportional to its displacement (like Hooke described), the particle undergoes simple harmonic motion. This was a turning point now SHM wasnt just an observation or an experiment. It was a motion that could be described precisely using mathematics and physics laws. As time passed and the 1800s approached, another great mind, Jean-Baptiste Joseph Fourier, took the study of motion even further. Fourier showed that any repeating (periodic) motion, no matter how complex, could be broken down into simple sine and cosine waves the very functions that describe SHM. This was revolutionary. Whether it was the vibration of a violin string, the sound of someones voice, or ripples in water, they could all be analyzed using simple harmonic components. His work connected SHM not just to mechanics, but to music, sound, and light shaping entire fields like acoustics and signal processing. As we moved into the 20th century, the concept of SHM became even more powerful. Scientists realized that molecules vibrate in SHM patterns, that electrons oscillate in atoms, and that radio waves travel as electromagnetic oscillations. Even buildings and bridges were analyzed for resonance, which is directly linked to SHM engineers needed to be sure that a building wouldnt collapse if its natural frequency matched the vibrations caused by wind or an earthquake. One famous example is the Tacoma Narrows Bridge in the USA, which collapsed in 1940. The bridge started swaying violently because strong winds matched the bridges natural frequency a deadly demonstration of resonance, a direct application of SHM. Periodic Motion: This is any motion that repeats itself at regular intervals of time. Examples include uniform circular motion, the orbital motion of planets, or even the bouncing of a ball between your hand and the ground (though the graph of its height versus time might look a bit different). The smallest interval of time after which the motion repeats is called its period (T). Its SI unit is the second. Frequency (): This is the reciprocal of the period (T) and represents the number of repetitions that occur per unit time. The relationship is = 1/T. The unit of frequency is s, also called hertz (Hz), where 1 Hz = 1 oscillation per second. Frequency is not necessarily an integer. Oscillatory Motion: This is a type of periodic motion where an object moves to and fro about a mean position. This mean position is often an equilibrium position where no net external force acts on the body. If displaced slightly from this position, a force tries to bring the body back, causing oscillations or vibrations. Examples include a pendulum of a wall clock, a ball in a bowl, or leaves oscillating in the breeze. Now, while every oscillatory motion is periodic, not every periodic motion needs to be oscillatory. For example, circular motion is periodic but not oscillatory. SHM is described as the simplest form of oscillatory motion. The key characteristic defining SHM relates to the force acting on the oscillating body: In SHM, the force on the body is directly proportional to its displacement from the mean position, which is also the equilibrium position. Furthermore, this force is always directed towards the mean position. This type of force is called a restoring force. This force law can be expressed mathematically as F(t) = -k x(t), where F is the force, x is the displacement from the mean position, and k is a constant. The negative sign indicates that the force is always opposite in direction to the displacement, pulling or pushing the particle back towards the equilibrium point (x=0). A system where the restoring force is proportional to the displacement (F = -kx) is also referred to as a linear harmonic oscillator. Mathematical Description of SHM In SHM, the restoring force always tries to bring the object back to its mean position, and is proportional to the displacement. \(\displaystyle F \propto -x \) The negative sign shows that the direction of the force is opposite to the displacement. Introducing a constant of proportionality kk, we write: \(\displaystyle F = -k x \tag{1}\) From Newtons second law of motion: \(\displaystyle F = m a = m \frac{d^2x}{dt^2} \tag{2}\) Where: m = mass of the object \(\displaystyle \frac{d^2x}{dt^2} \)= acceleration Combine Equations (1) and (2), Equating both expressions for force: \(\displaystyle m \frac{d^2x}{dt^2} = -k x\) Divide both sides by m: \(\displaystyle\frac{d^2x}{dt^2} + \frac{k}{m} x = 0 \tag{3}\) Let: \(\displaystyle\omega^2 = \frac{k}{m}\) Now equation (3) becomes: \(\displaystyle \frac{d^2x}{dt^2} + \omega^2 x = 0 \tag{4}\) This is the standard differential equation of SHM. General Solution of the Differential Equation, The solution of this second-order differential equation is: \(\displaystyle x(t) = A \cos(\omega t) + B \sin(\omega t) \tag{5}\) Where: A and B are constants (depend on initial conditions) \(\displaystyle\omega\) = angular frequency t = time This is the general form of SHM. Express in a Single Cosine Function, Using trigonometric identity, this expression can also be written as: \(\displaystyle x(t) = C \cos(\omega t + \phi) \tag{6}\) Where: C = amplitude = \(\displaystyle \sqrt{A^2 + B^2}\) \(\displaystyle \phi \)= phase constant = \(\displaystyle\tan^{-1} \left(-\frac{B}{A} \right)\) Final Equation of SHM, \(\displaystyle x(t) = A \cos(\omega t + \phi)\) Where: x(t) = displacement at time tt A = amplitude = angular frequency =\(\displaystyle\sqrt{\frac{k}{m}}\) = phase constant The displacement of a particle undergoing linear simple harmonic motion can be represented by a sinusoidal function of time. One common form is: x(t) = A cos (t +) x(t): This is the displacement of the particle from its equilibrium position at a given time t. Displacement here is used in a general sense, referring to the change in the physical property under consideration over time, not just position. It can take both positive and negative values. A: This is the Amplitude of the motion. It is a positive constant representing the magnitude of the maximum displacement of the particle in either direction from the mean position. (t +): This entire quantity is called the phase of the motion. It describes the state of motion at a given time. : This is the phase constant (or phase angle). Its a constant value that depends on the initial conditions of the motion (displacement and velocity at t=0). It signifies the initial conditions. : This is the angular frequency of the motion. It is related to the period T by the equation = 2/T. Its SI unit is radians per second. The angular frequency is also related to the spring constant (k) and mass (m) in a linear oscillator by = (k/m). The function f(t) = A cos(t +) is periodic with period T = 2/. Similarly, f(t) = A sin(t) or a linear combination like f(t) = A sin(t) + B cos(t) are also periodic with the same period T. Notably, any periodic function can be expressed as a superposition of sine and cosine functions of different time periods. Velocity in SHM In simple harmonic motion (SHM), an object moves back and forth around a central point (called the mean position). You already know that its displacement changes with time in a wave-like pattern. But how fast does it move at each point? Thats where velocity comes in and it behaves in a very interesting way. Lets say you have a mass attached to a spring, and you pull it to one side and release it. The mass starts oscillating moving to and fro. When the mass reaches the end points (maximum displacement, or amplitude), it stops for a moment before reversing direction. That means its velocity is zero at the extreme positions. As it starts coming back towards the center, it speeds up. At the mean position, the object is moving the fastest. So, in SHM: Velocity is maximum at the mean position Velocity is zero at the extreme positions We already know that in SHM, displacement is given by: \(\displaystyle x(t) = A \cos(\omega t + \phi)\) To find velocity, we take the derivative of displacement with respect to time: \(\displaystyle v(t) = \frac{dx}{dt} = -A \omega \sin(\omega t + \phi)\) So, the equation for velocity becomes: \(\displaystyle v(t) = -\omega A \sin(\omega t + \phi)\) This tells us how velocity varies with time. The negative sign shows that the direction of velocity is opposite to that of displacement when moving toward the mean position. Velocity in terms of displacement: Using energy conservation and trigonometry, we can also write velocity as: \(\displaystyle v = \omega \sqrt{A^2 x^2}\) This form helps us understand that velocity depends on how far the particle is from the mean position. When x = A or -A, velocity is 0. When x = 0, velocity is maximum, \(\displaystyle v_{\text{max}} = \omega A\) Graphical Understanding Displacement, Velocity and acceleration in SHM. Interpretation of the Graphs: The displacement graph is a cosine wave. The velocity graph is a sine wave (with negative sign). Notice that the velocity wave is shifted by a quarter cycle (/2 radians) from the displacement wave. At the peak of displacement, velocity is zero. At zero displacement (mean position), velocity is maximum. Physical Meaning: Lets relate this to real life. Imagine pushing a child on a swing: At the highest point (extreme position), the child momentarily stops zero velocity. As they come down toward the center, they speed up velocity increases. At the bottom (mean position), theyre moving the fastest maximum velocity. Then, as they rise again, they slow down velocity decreases and becomes zero at the next extreme. This is exactly how velocity behaves in SHM. The instantaneous velocity v(t) of a particle in SHM is given by the first derivative of the displacement x(t): v(t) = -A sin (t +) The maximum speed (velocity amplitude) is vm = A. The velocity of the oscillating particle varies between A. The velocity lags behind the displacement by a phase angle of /2. Velocity is zero at the extreme positions (maximum displacement) and maximum when the particle is at the mean position (zero displacement). Acceleration in SHM When we talk about motion, we usually think about how fast something moves thats velocity. But in simple harmonic motion (SHM), theres another important aspect to understand: acceleration. In SHM, acceleration plays a special role because it is directly responsible for the motion. Lets imagine a mass hanging from a spring, or a pendulum swinging from side to side. These objects go back and forth repeatedly they oscillate. At every moment, theres a force acting on them that tries to pull them back toward the central position, called the mean position. This force is called a restoring force, and it is always trying to bring the object back to equilibrium. Now, according to Newtons Second Law, force causes acceleration: F = ma. But in SHM, the force itself depends on how far the object is from the center. Thats given by: F = -kx Combining these two, we get: \(\displaystyle ma = -kx \quad \Rightarrow \quad a = -\frac{k}{m}x\) We introduce angular frequency ; where: \(\displaystyle\omega^2 = \frac{k}{m}\) Now, we can write the acceleration in SHM as: \(\displaystyle a(t) = -\omega^2 x(t)\) This equation tells us two very important things: Acceleration is directly proportional to displacement if you double the displacement, acceleration doubles. The negative sign means the direction of acceleration is always opposite to displacement if the object is to the right, the acceleration is to the left. What does this mean during motion? When the object is at the maximum displacement (farthest from center), the acceleration is maximum because its being pulled back strongly. When the object passes through the mean position, the displacement is zero, so acceleration is also zero. Thats because no force is acting to pull it back at that exact moment but its moving the fastest here! As it moves to the opposite side, the acceleration changes direction, still pointing toward the center. So, acceleration in SHM is like a push that gets stronger as the object moves away from the center, and reverses direction every time the object crosses the mean position. The instantaneous acceleration a(t) is given by the first derivative of the velocity v(t) or the second derivative of the displacement x(t): a(t) = -A cos (t +) Substituting x(t) = A cos(t +), we get the important relationship: a(t) = -x(t) This shows that in SHM, the acceleration is proportional to the displacement and is always directed towards the mean position. The maximum acceleration (acceleration amplitude) is am = A. When displacement is maximum positive, acceleration is maximum negative, and vice versa. When displacement is zero, acceleration is also zero. To understand Simple Harmonic Motion (SHM) more deeply, it helps to explore a surprising yet beautiful idea: SHM is just a shadow of uniform circular motion. This connection was first noticed by Galileo, and later developed into a powerful mathematical model that helps us visualize and understand oscillations in a new way. Galileo observed the moons of Jupiter appearing to move back and forth in SHM relative to the planet, and it is now known that they move in nearly circular orbits. What he saw was the projection of their uniform circular motion. Lets begin with a simple setup. Imagine a particle moving in a uniform circular motion that means it is going around a circle at a constant speed. Suppose this motion happens in a horizontal circle, like a stone tied to a string and whirled in a perfect circle. Now, imagine watching this motion from the side from a point where you can only see the projection of the particle on a wall behind it. What you see is not a circle, but rather a to-and-fro motion the particle appears to move back and forth in a straight line. This back-and-forth projection of circular motion is exactly what we call Simple Harmonic Motion. Consider a particle moving in a circle of radius A with constant angular velocity . At any time t, the position of the particle makes an angle = t with the horizontal axis. If we project the position of the particle onto the horizontal diameter of the circle, we get: \(\displaystyle x(t) = A \cos(\omega t)\) This is the exact equation of displacement for SHM. So, the horizontal projection of the circular motion follows a cosine wave just like a mass on a spring or a pendulum swinging back and forth. Lets go further. In circular motion, although the speed is constant, the direction of motion changes continuously, which means the particle has acceleration (called centripetal acceleration) pointing toward the center of the circle. When we observe the projection of this acceleration along the diameter, we get: \(\displaystyle a(t) = -\omega^2 x(t)\) This is also the defining equation for acceleration in SHM. So, what does this mean? It means that we can treat SHM as a one-dimensional slice or shadow of a uniform circular motion. The oscillating mass on a spring moves just like the horizontal projection of a particle moving uniformly around a circle. This connection isnt just a mathematical trick its an extremely helpful way to visualize SHM. It helps us understand phase angles (the angle in circular motion becomes the phase in SHM), the idea of amplitude (the radius of the circle), and the smooth, wave-like nature of oscillatory motion. To imagine this in real life, think of how the moon appears to move across the sky though its moving in a circular orbit, from our point of view on Earth, it seems to move back and forth in a regular way. Similarly, if you spin a ball tied to a string in a circle and observe its shadow on a wall, the shadow will oscillate just like a mass in SHM. To understand the energy in simple harmonic motion (SHM), lets imagine a simple system: a mass mm attached to a spring on a smooth horizontal surface. When you pull the mass to one side and release it, it starts oscillating back and forth. While it moves, it continuously exchanges energy between potential energy (stored in the spring) and kinetic energy (due to motion). The total mechanical energy in SHM, however, always remains constant, as there is no friction or energy loss. Lets begin with what we know about the motion. The displacement of the object in SHM is given by the equation: \(\displaystyle x(t) = A \cos(\omega t + \phi)\) To find the kinetic energy, we first need the velocity of the particle. We take the derivative of displacement with respect to time: \(\displaystyle v(t) = \frac{dx}{dt} = -A \omega \sin(\omega t + \phi)\) Now, the kinetic energy K of the particle is given by the formula: \(\displaystyle K = \frac{1}{2}mv^2\) Substitute the expression of velocity into this: \(\displaystyle K = \frac{1}{2}m (-A \omega \sin(\omega t + \phi))^2 = \frac{1}{2}m A^2 \omega^2 \sin^2(\omega t + \phi)\) This expression shows that kinetic energy varies with time its not constant. When the particle is at the mean position, the sine function becomes 1\pm 1, and hence kinetic energy is maximum. When the particle is at the extreme position (maximum displacement), sine becomes zero, and kinetic energy is zero. Now lets derive the potential energy stored in the spring. In SHM, the restoring force is F = -kx, and the potential energy U stored in the spring when it is compressed or stretched by a displacement xx is given by: \(\displaystyle U = \frac{1}{2}kx^2\) Substitute \(\displaystyle x(t) = A \cos(\omega t + \phi)\) into this equation: \(\displaystyle U = \frac{1}{2}k (A \cos(\omega t + \phi))^2 = \frac{1}{2}k A^2 \cos^2(\omega t + \phi)\) Now recall that \(\displaystyle\omega^2 = \frac{k}{m}\), so we can write \(\displaystyle k = m \omega^2\). Substituting this in: \(\displaystyle U = \frac{1}{2} m \omega^2 A^2 \cos^2(\omega t + \phi)\) So, the potential energy also varies with time. It becomes maximum at the extreme positions (where cosine is 1) and becomes zero at the mean position (where cosine is 0). To find the total mechanical energy E, we add kinetic and potential energy: E = K + U \(\displaystyle E = \frac{1}{2} m A^2 \omega^2 \sin^2(\omega t + \phi) + \frac{1}{2} m A^2 \omega^2 \cos^2(\omega t + \phi)\) Factor out the common term: \(\displaystyle E = \frac{1}{2} m A^2 \omega^2 (\sin^2(\omega t + \phi) + \cos^2(\omega t + \phi))\) From trigonometry, we know: \(\displaystyle \sin^2\theta + \cos^2\theta = 1\). So the total energy becomes: \(\displaystyle E = \frac{1}{2} m A^2 \omega^2\) This is a constant. It doesnt depend on time. It tells us that while kinetic and potential energy in SHM keep changing from one to the other during motion, their total sum remains fixed at every moment. The energy is simply shuttling back and forth like a perfectly coordinated dance between movement and position, between speed and stretch. This constancy of energy is what keeps the system oscillating smoothly and predictably. One of the simplest and most common examples of a system that executes simple harmonic motion (SHM) is a spring-mass system. This setup not only helps us understand SHM clearly but also forms the foundation for studying oscillations in mechanical and physical systems. Imagine a spring placed on a smooth horizontal table, and a block of mass mm is attached to one end of the spring. The other end of the spring is fixed to a wall. Now, if you pull the block slightly and release it, youll notice something interesting: the block starts to move back and forth in a rhythmic, repetitive motion. This back-and-forth motion is an example of simple harmonic motion, provided the spring obeys Hookes law and theres no friction. Lets understand what happens when we stretch the spring. According to Hookes Law, the force exerted by a spring is: F = -kx Here, x is the displacement of the mass from the equilibrium position, kk is the spring constant (which tells us how stiff the spring is), and the negative sign indicates that the force always acts in the direction opposite to the displacement its a restoring force. This force is what pulls the mass back toward the mean position when it is displaced. And this is exactly the condition needed for SHM: a restoring force that is directly proportional to displacement but acts in the opposite direction. Now, using Newtons second law,F = ma, we can write: ma = -kx \(\displaystyle \Rightarrow a = -\frac{k}{m}x\) This is the defining equation of SHM. It tells us that the acceleration is proportional to the negative of displacement the more you pull the spring, the stronger the force pulling it back. Next, lets look at how fast the system oscillates. This depends on two things: the mass mm of the object and the stiffness kk of the spring. A heavier mass oscillates more slowly, while a stiffer spring makes the system oscillate faster. The angular frequency of oscillation is: \(\displaystyle\omega = \sqrt{\frac{k}{m}}\) From angular frequency, we can calculate the time period, which is the time taken to complete one full oscillation: \(\displaystyle T = 2\pi \sqrt{\frac{m}{k}}\) This formula shows that the time period doesnt depend on how far you pull the spring it only depends on the mass and the spring constant. This is why SHM is called isochronous the time for each cycle remains the same. To make this more visual, imagine compressing the spring and letting it go. The block moves quickly toward the mean position, gains speed, passes through the equilibrium point with maximum velocity, then slows down as the spring stretches on the other side, comes to a stop at the extreme point, and then reverses direction. This repeating motion speeding up and slowing down continues as long as theres no friction to remove energy. The same principle applies in the vertical spring system too. If you hang a mass from a vertical spring and displace it downward slightly and release, it will oscillate up and down around the new equilibrium position. The same equations apply, because gravity only shifts the equilibrium, it doesnt affect the oscillation itself. One of the most familiar examples of oscillatory motion is a simple pendulum. Its something weve all seen whether its the slow swinging of a hanging clocks arm or a string with a weight at the bottom swaying gently. Though it appears very simple, the motion of a pendulum actually hides beautiful physics, and under certain conditions, it executes simple harmonic motion (SHM). Lets understand how. Imagine a small metal ball called a bob tied to a long, inextensible and massless string of length LL, suspended from a fixed support. When the bob hangs vertically downward, its in its equilibrium position. Now, pull the bob slightly to one side and let it go. What happens? It swings to and fro back and forth through the lowest point. This motion is periodic and seems similar to SHM. But is it SHM? Lets examine what kind of force is acting on it. When the bob is displaced by a small angle a from the vertical, it experiences a restoring force due to gravity. The component of the gravitational force that causes the pendulum to return to its mean position is: \(\displaystyle F = -mg \sin(\theta)\) This force is always directed toward the center toward equilibrium and tries to bring the bob back. However, theres a catch. SHM requires the restoring force to be directly proportional to displacement, not to the sine of an angle. Heres where the magic of approximation helps. For small angles (less than about 10), we can use the mathematical approximation: \(\displaystyle\sin(\theta) \approx \theta \quad \text{(in radians)}\) So now the force becomes: \(\displaystyle F = -mg \theta\) But we want this in terms of linear displacement. The arc length ss (which is how far the bob has moved along the circular path) is related to by: \(\displaystyle s = L \theta \Rightarrow \theta = \frac{s}{L}\) So the restoring force becomes: \(\displaystyle F = -mg \cdot \frac{s}{L}\) Using Newtons second law: \(\displaystyle ma = -mg \cdot \frac{s}{L} \Rightarrow a = -\frac{g}{L} s\) This is the defining equation of SHM: acceleration is directly proportional to displacement and directed toward the mean position. Hence, for small angular displacements, the motion of a simple pendulum is simple harmonic. From this equation, we can identify the angular frequency : \(\displaystyle\omega^2 = \frac{g}{L} \Rightarrow \omega = \sqrt{\frac{g}{L}}\) And from that, the time period of one complete oscillation is: \(\displaystyle T = 2\pi \sqrt{\frac{L}{g}}\) This is a beautiful result the time period of a simple pendulum depends only on the length of the string and the acceleration due to gravity, and not on the mass of the bob or the amplitude (as long as the amplitude is small). So, two pendulums of the same length will swing with the same rhythm no matter what their mass is. Also Read: Keplers Law of Planetary Motion Simple harmonic motion (SHM) is a specific type of oscillation thatoccurs when acceleration is proportional to displacement from a fixed point and in the opposite directionAn object is said to performsimple harmonic oscillationswhen all of the following apply:The oscillations are periodic (repeating)There is a central equilibrium point known as the fixed pointThe object's displacement, velocity and acceleration change continuouslyThere is arestoring forcealways directed towards the fixed pointThe magnitude of the restoring force is proportional to the displacementThe restoring force causes the accelerationTherestoring forceand theaccelerationmust always be:Directed towards the equilibrium position, and hence, in theoppositedirection to thedisplacementDirectlyproportionalto thedisplacementa xWhere:a= acceleration (m s2)x= displacement (m)Restoring force, acceleration and displacementForce, acceleration and displacement of a simple pendulum in SHMExamples of simple harmonic motionExamples of oscillators that undergo SHM are:The pendulum of a clockA child on a swingThe vibrations of a bowlA bungee jumper reaching the bottom of his fallA mass on a springGuitar strings vibratingA ruler vibrating off the end of a tableThe electrons in alternating current flowing through a wireThe movement of a swing bridge when someone crossesA marble dropped into a bowlExamples of simple harmonic motionA pendulum, bungee jumper, swing bridge, vibrations in a prayer bowl, a swing, a ball rolling up and down the sides of a bowl and a spring are all examples of simple harmonic oscillations.An example of not SHMA person jumping on a trampoline is not an example of simple harmonic motion because:Therestoring forceon the person is not proportional to theirdisplacementfrom the equilibrium position and always acts downWhen the person isnot in contactwith the trampoline, the restoring force is equal to their weight, which is constantThisdoes not change, even if they jump higherThe restoring force of the person bouncing is equal to their weight and always acts downwardsPage 2An oscillation is defined as follows:The repetitive variation with time t of the displacement x of an object about the equilibrium position (x = 0)Pendulum oscillation on a displacement-time graphA pendulum oscillates between A and B. On a displacement-time graph, the oscillating motion of the pendulum is represented by a wave, with an amplitude equal to x0Equilibrium position (x = 0)is the position when there is no resultant force acting on an objectDisplacement (x)of a wave is the distance of a point on the wave from its equilibrium positionIt is a vector quantity; it can be positive or negative and it is measured in metres (m)Amplitude (x0) is the maximum value of the displacement on either side of the equilibrium position and is known as the amplitude of the oscillationAmplitude is measured in metres (m)Wavelength () is the length of one complete oscillation measured from the same point on two consecutive wavesWavelength is measured in metres (m)Wavelength and amplitude on a displacement-time graphDiagram of wavelength and amplitude of a wavePeriod (T) or time period, is thetime interval for one complete repetition and it is measured in seconds (s)Simple harmonic oscillations have a constant periodTime period can be calculated in terms of both frequency and angular frequency by the equations:Where:T= Time period (s)f = frequency (Hz) = angular frequency (rad s1)Time period on a displacement-time graphDiagram showing the time period of a waveFrequency (f) is the number of oscillations per second measured in hertz (Hz)Hz have the SI units of per second s1Angular Frequency()is the rate of change of angular displacement with respect to timeAngular frequency is measured in rad s1It is given by the equations:Where:= angular frequency (rad s1)T= time period (s)f = frequency (Hz)Phase differencePhase is a useful way to consider wave behaviourThe phase of a wave can be measured in terms of:Fractions of wavelengthDegreesRadiansOne complete oscillation is:1 wavelength3602 radiansWavelength and amplitude A of a travelling waveThephase differencebetween two waves is a measure ofhow much a point or a wave is in front or behind anotherThis can be found from the relative position of the crests or troughs of two different waves of the same frequencyWhen the crests of each wave, or the troughs of each wave are aligned, the waves arein phaseWhen the crest of one wave aligns with the trough of another, they are inantiphaseThe diagram below shows thatthe green wave leadsthe purple wave by the purple wave lagsbehind the green wave by A phase difference of 1/4 wavelengthTwo waves out of phasePhase difference can be described as in phase or in anti-phase:In phaseis360oor 2 radiansIn anti-phaseis180oor radiansPage 3Exam code: 97021 hour8 questions1a2 marks1b5 marksIdentify the correct definition by drawing lines between the properties of oscillations and their definition.Properties of OscillationsDefinition of PropertiesDisplacementThe rate of change of angular displacement with respect to timeAmplitudeThe distance of an oscillator from its equilibrium positionAngular FrequencyThe time taken for one complete oscillationFrequencyThe maximum displacement of an oscillator from its equilibrium positionTime PeriodThe number of oscillations per unit time1c3 marksDefine simple harmonic oscillation.1d4 marksUse the words in the box below to correctly label the diagram of an oscillating pendulum in Fig 1.1.displacement of massmassaccelerationrestoring forceequilibrium positionFig. 1.1Did this page help you?2a2 marksThe graph in Fig. 1.1 shows that the acceleration of an object is directly proportional to the negative displacement.Fig. 1.1Label the two axis of the graph on Fig. 1.1.2b2 marksThe graphs in Fig. 1.3 show an oscillator starting at the equilibrium position and an oscillator starting at the maximum displacement.Fig. 1.3Identify by writing next to the graphs on Fig 1.3 the correct name of the starting position of the oscillator.2c4 marksThe equation below defines how the speed of an oscillator changes with the displacement of the oscillator.Identify the variables in the equation by stating the variable and the quantity it represents in the space below.Did this page help you?3a4 marksA pendulum undergoes small-angle oscillations.State and explain the equation that defines simple harmonic motion.3b4 marksSketch a graph to show the variation of displacement against time for one swing of the pendulum.Start the time at zero seconds and mark the amplitude of the oscillation .3c3 marksThe time taken for 10 oscillations is found to be 12.0 s.Determine the frequency of the oscillation.3d2 marksGive two other examples of objects that perform simple harmonic motion.Did this page help you?1a1 markA small wooden cuboid block of massmfloats in water, as shown in Fig. 1.1.The top face of the block is horizontal and has an areaA. The density of the water is.The block is displaced downwards as shown in Fig. 1.2 so that the surface of the water is now higher up the block.State and explain the direction of the resultant force acting on the wooden block in this position.1b2 marksThe block in(a)is now released so that is oscillates vertically.The resultant forceFacting on the block is given bywheregis the gravitational field strength andxis the vertical displacement of the block from the equilibrium position.Explain why the oscillations of the block are simple harmonic.1c3 marksUse the equation from(b)to obtain an expression for the angular frequency of the oscillations of the block.1d4 marksThe block is now placed in a liquid with a lower density. The block is displaced and released so that it oscillates vertically. The variation with displacement xof the accelerationaof the block is measured for the first half of the oscillation, as shown in Fig. 1.3.(i) Explain why the maximum negative displacement of the block is not equal to its maximum positive displacement.[1](ii) The mass of the block is 0.65 kg.Use Fig. 1.3. to determine the decrease in energy of the oscillation for the first half of the oscillation.E= .... J [3]Did this page help you?2a2 marksA pendulum consists of a bob (small plastic sphere) attached to the end of a piece of wire. The other end of the wire is attached to a fixed point. The bob oscillates with small oscillations about its equilibrium position, as shown in Fig. 1.1.The lengthLof the pendulum, measured from the fixed point to the centre of the bob, is 1.56 m.The accelerationaof the bob varies with its displacementxfrom the equilibrium position as shown in Fig. 1.2.State how Fig. 1.2 shows that the motion of the pendulum is simple harmonic.2b2 marksUse Fig. 1.2 from(a)to calculate the angular frequency of the oscillations.= .... rad s12c2 marksThe angular frequency is related to the lengthLof the pendulum bywherekis a constant.Use your answer from(b)to determinek. Give a unit for your answer.k= .... unit ....2d2 marksWhilst the pendulum is oscillating, the length of the string is decreased in such a way that the total energy of the oscillations remains constant.Suggest and explain the qualitative effect of this change on the amplitude of the oscillations.Did this page help you?3a2 marksAn object is suspended from a spring that is attached to a fixed point as shown in Fig. 1.1.The object oscillates vertically with simple harmonic motion about its vertical position.State the defining equation for simple harmonic motion. Identify the meaning of each of the symbols used to represent Physical quantities.3b3 marksThe variation with displacement xfrom the equilibrium position of the velocityv of the object is shown in Fig. 1.2.Use Fig. 1.2 to:(i) Determine the amplitudex0 of the oscillationsx0 = ... m [1](ii) Determine the angular frequency of the oscillations.[2]3c4 marksThe oscillations of the object are now heavily damped.(i) State what is meant by damping. [2](ii) Assume that the damping does not change the angular frequency of the oscillations.On Fig. 1.2, sketch the variation withxofv when the amplitude of the oscillations is 0.03 m.[2]Did this page help you?1a4 marksA mass of 0.42 kg is attached to a spring and the system is made to oscillate with simple harmonic motion (SHM) on a horizontal, frictionless surface. The mass passes through the equilibrium position200times per minute.The kinetic energy of the mass as it passes through the equilibrium position is500mJ.There are two points where the restoring force acting on the mass is at its maximum.Show that the distance between these points is approximately 29 cm.1b2 marksSketch a graph to show how the velocity of the mass varies with time. Label the graph with any suitable values.1c2 marksFind the distance of the mass from the equilibrium position when the speed of the block is0.8m s11d3 marksThe experiment is moved to planet X. The gravitational acceleration on planet X is g. It is known that = 2. Another change is that three more identical springs are placed in parallel to the original spring.The period of a spring undergoing simple harmonic oscillation is given by:wherem is the mass of the object at the end of the spring andk is the spring constant.Describe, without calculations, how these changes affect the frequency with which the mass oscillates.Did this page help you?2a3 marksA small metal pendulum bob is suspended at rest from a fixed point with a length of thread of negligible mass. Air resistance is negligible. The pendulum begins to oscillate. Fig. 1.1 shows the variation of kinetic energy of the pendulum bob with time.Fig. 1.1(i) Label on the graph with the letter X a point where the speed of the pendulum is half that of its initial speed.[1](ii) Calculate, in metres, the length of the thread, if the periodT is given by the equation:wherel is the pendulum length andg is the acceleration of free fall.[2]2b3 marksFig. 1.2shows how the kinetic energy of the pendulum varies with displacement.Fig. 1.2(i) Sketch on the diagram above a graph to show how the potential energy of the pendulum varies with displacement.[1](ii) Calculate the mass of the pendulum bob.[2]2c2 marksCalculate the magnitude of the maximum force upon the pendulum.Did this page help you?Page 4PolarisationSelect a download format for PolarisationMultiple Choice QuestionsScroll for moreDiffractionSelect a download format for DiffractionMultiple Choice QuestionsScroll for moreConcept of a Magnetic FieldRepresenting Magnetic Fields Science Astronomy Newtons laws of motion, three statements describing the relations between the forces acting on a body and the motion of the body, first formulated by English physicist and mathematician Isaac Newton, which are the foundation of classical mechanics. basketball; Newton's laws of motionWhen a basketball player shoots a jump shot, the ball always follows an arcing path. The ball follows this path because its motion obeys Isaac Newton's laws of motion.Newtons first law states that if a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line at constant speed unless it is acted upon by a force. In fact, in classical Newtonian mechanics, there is no important distinction between rest and uniform motion in a straight line; they may be regarded as the same state of motion seen by different observers, one moving at the same velocity as the particle and the other moving at constant velocity with respect to the particle. This postulate is known as the law of inertia. The law of inertia was first formulated by Galileo Galilei for horizontal motion on Earth and was later generalized by Ren Descartes. Although the principle of inertia is the starting point and the fundamental assumption of classical mechanics, it is less than intuitively obvious to the untrained eye. In Aristotelian mechanics and in ordinary experience, objects that are not being pushed tend to come to rest. The law of inertia was deduced by Galileo from his experiments with balls rolling down inclined planes. For Galileo, the principle of inertia was fundamental to his central scientific task: he had to explain how is it possible that if Earth is really spinning on its axis and orbiting the Sun, we do not sense that motion. The principle of inertia helps to provide the answer: since we are in motion together with Earth and our natural tendency is to retain that motion, Earth appears to us to be at rest. Thus, the principle of inertia, far from being a statement of the obvious, was once a central issue of scientific contention. By the time Newton had sorted out all the details, it was possible to accurately account for the small deviations from this picture caused by the fact that the motion of Earths surface is not uniform motion in a straight line (the effects of rotational motion are discussed below). In the Newtonian formulation, the common observation that bodies that are not pushed tend to come to rest is attributed to the fact that they have unbalanced forces acting on them, such as friction and air resistance.

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