

Question:

You're standing at the end of a springboard, bouncing gently up and down without leaving the board's surface. If you bounce harder, the time it takes for each bounce will

1. Become shorter
2. Become longer
3. Remain the same

Non-Repetitive Clocks

- Common in antiquity
 - Sandglasses
 - Water clocks
 - Candles
- Require frequent operator intervention
- Operator requirement limits accuracy

Repetitive Clocks

- Developed about 500 years ago
- Require no operator intervention
- Limited only by accuracy of repetitive motion
- Motion mustn't depend on external influences:
 - Temperature, air pressure, time of day, ...
 - The clock's store of energy (wound, unwound, ...)
 - The observation process

Terminology

- Period – time needed to complete a full cycle of a repetitive motion.
- Frequency – number motion cycles completed in a unit of time
- Amplitude – the spatial extent of a repetitive motion.

Harmonic Oscillator

- Any system with a stable equilibrium and a restoring force that's proportional to distortions away from that equilibrium
- A period that's independent of amplitude
- Examples:
 - Pendulum
 - Mass on a spring

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Limits on Accuracy

- Fundamental limits:
 - Decay rate limits precision of period
- Practical Limits:
 - Sustaining motion can influence period
 - Observing period can influence period
 - Sensitivity to temperature, pressure, wind, ...

Pendulum Clocks

- Distance from pivot to center of gravity
 - Temperature stabilized
 - Adjustable for local gravity
- Air resistance minimized
- Swinging is sustained and measured with minimal perturbation on motion

Balance Ring Clocks

- A torsional spring causes a balanced ring to twist back and forth as a harmonic oscillator
- Gravity exerts no torque about the ring's pivot, so it has no influence on the period
- Twisting is sustained and measured with minimal perturbation on motion

Quartz Crystals

- Crystalline quartz is a harmonic oscillator
 - Crystal provides the inertial mass
 - Stiffness provides restoring force
- Decay rate is extremely slow
- Fundamental accuracy is very high
- Quartz is piezoelectric: mechanical and electrical properties are coupled

Quartz Clocks

- Electronic system starts crystal vibrating
- Vibrating crystal triggers electronic counter
- Essentially insensitive to gravity, temperature, pressure, and acceleration
- Slow vibration decay makes clocks accurate

Atomic Clocks 1

- Electrons orbit the nucleus of an atom
- Only certain orbits are possible due to quantum mechanical nature of universe
- Associated with each these orbitals is a specific amount of total energy
- Hopping from one orbital to another requires or releases a fixed amount of energy

Atomic Clocks 2

- Associated with a certain amount of energy is a specific frequency
- Light of a specific frequency carries a certain amount of energy per packet.
- Atoms can only emit or absorb light of specific frequencies: the ones that carry just the right energy to shift electrons between orbitals

Atomic Clocks 3

- Atomic clocks study the interactions of atoms with light
- The atoms act as frequency references for the light: only the right frequency light affects the atoms
- Atomic clocks keep time by with the help of this frequency stabilized light