Clocks

Question:

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

Observations About Clocks

- They divide time into uniform intervals
- They count the passage of those intervals
- Some involve obvious mechanical motions
- Some seem to involve no motion at all
- They require an energy source
- They have limited accuracy

Non-Repetitive Clocks

- Measures a single interval of time
  - Sandglasses
  - Water clocks
  - Candles
- Common in antiquity
- Poorly suited to subdividing the day
  - Requires frequent operator intervention
  - Operator requirement limits accuracy

Repetitive Motions

- An object with a stable equilibrium tends to oscillate about that equilibrium
- This oscillation entails at least two types of energy – kinetic and a potential energy
- Once the motion has been started, it repeats spontaneously many times

Repetitive-Motion Clocks

- Developed about 500 years ago
- Require no operator intervention
- Accuracy limited only by repetitive motion
- Motion shouldn't depend on externals:
  - temperature, air pressure, time of day
  - clock's store of energy
  - mechanism that observes the motion

Some Specifics

- Terminology
  - Period: time of full repetitive motion cycle
  - Frequency: cycles completed per unit of time
  - Amplitude: peak extent of repetitive motion
- Application
  - In an ideal clock, the repetitive motion's period shouldn't depend on its amplitude

A Harmonic Oscillator

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

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Limits to the Accuracy

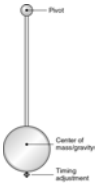
- Fundamental limits:
  - Oscillation decay limits preciseness of period
- Practical Limits:
  - Sustaining motion can influence the period
  - Observing the period can influence the period
  - Sensitivity to temperature, pressure, wind, …

Pendulums

- Pendulum (almost) a harmonic oscillator
- Period proportional to $(\text{length}/\text{gravity})^{1/2}$
- Period (almost) independent of amplitude

Pendulum Clocks

- Pendulum is clock's timekeeper
- For accuracy, the pendulum
  - pivot–center-of-gravity distance is
    - temperature stabilized
    - adjustable for local gravity effects
  - streamlined to minimize air drag
  - motion sustained, measured gently
- Limitation: clock mustn't move



Balance Ring Clocks

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

Quartz Oscillators Part 1

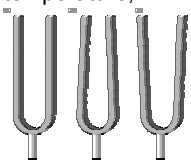
- Crystalline quartz is a harmonic oscillator
  - Crystal provides the inertial mass
  - Stiffness provides restoring force
- Oscillation decay is extremely slow
- Fundamental accuracy is very high

Quartz Oscillators Part 2

- Quartz is piezoelectric
  - mechanical and electrical changes coupled
  - motion is induced and measured electrically

Quartz Clocks

- Electronic system starts crystal vibrating
- Vibrating crystal triggers electronic counter
- Nearly insensitive to gravity, temperature, pressure, and acceleration
- Slow vibration decay leads to precise period
- Tuning-fork shape yields slow, efficient vibration



Atomic Clocks Part 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
- Quantum leap from one orbital to another involves a specific amount of energy

Atomic Clocks Part 2

- Associated with a specific 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 Part 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

Summary About Clocks

- Most clocks involve harmonic oscillators
- Amplitude independence aids accuracy
- Clock sustains and counts oscillations
- Oscillators that lose little energy work best