Mon: Paper – produce final draft
– details about grading + general writing issues
in email from Tuesday October 5 (~10am)

Fri: Cover Mondschein 86 – 92
Barnett 88 – 94

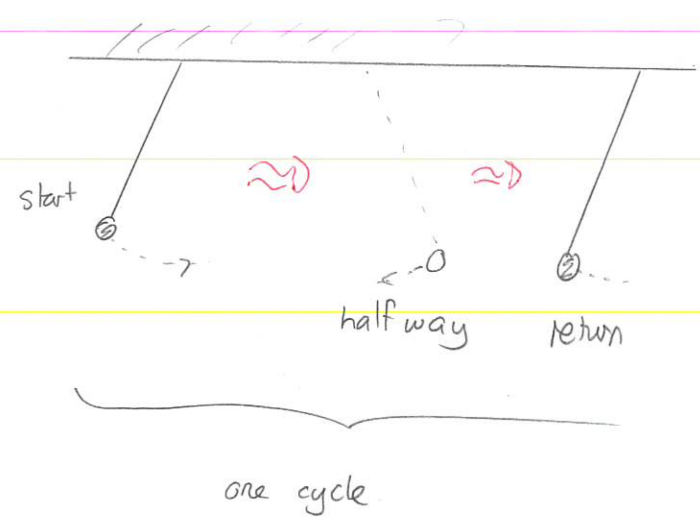
Pendulums in clocks

A pendulum is a device that swings back + forth primarily under the influence of Earth's gravity. Such an object could be used to regulate the timing in a mechanical clock. The primary advantage over a verge and foliot is that the pendulum has an inherent natural rate of oscillation.

Much of the technical understanding of such motion refers to a cycle of motion which is a single basic repetition of the motion.

From a timing perspective, the crucial issue is:

What determines the time taken to complete one cycle of oscillation?



1 Basic pendulum motion

Recall that the period of oscillation is the time that an oscillator takes to complete one cycle of motion. For a pendulum a cycle is one complete swing back and forth. The frequency of oscillation is the number of cycles completed in one second. These are related by

$$\text{frequency} = \frac{1}{\text{period}}$$

and

$$\text{period} = \frac{1}{\text{frequency}}.$$

a) You will be given a pendulum. Hold it suspended, noting the suspension point, let it start swinging and measure the total time that it takes to complete ten cycles. Determine the period and frequency of your pendulum.

Time for 10 cycles = 11.5s

↳ divide by 10

⇒ Time for one cycle = period = 1.15s

frequency = 0.87 Hz

b) Using the same pendulum and the same suspension point, have the pendulum swing with a somewhat larger amplitude. Use the procedure above to determine the period and frequency of the pendulum.

Time for 10 cycles = 11.4s

Period = 1.14s

frequency = 0.88 Hz

c) Does the period of the pendulum depend on the amplitude of the swing, assuming that the suspension point is the same?

They are very similar. It seems independent of the length

d) Now, shorten the length of the pendulum string or "rod" to about half of what it had been. Release the pendulum and allow it to swing. Without doing any timing, does the period appear to be the same as, longer than or shorter than it had been previously?

It seems that the period is shorter.

e) Measure the period and determine the period and the frequency of the shorter length pendulum.

Time for ten cycles = 9.0s

Period = 0.90s

frequency = 1.1Hz

f) Based on your observations does the period of the pendulum increase, decrease or remain constant when the length is shortened? Does the frequency of the pendulum increase, decrease or remain constant when the length is shortened?

Period decreases

Frequency increases.

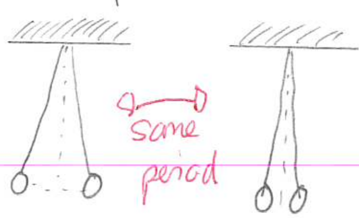
This experiment demonstrates two important facts about a pendulum:

1) the period of the pendulum depends on the length of the pendulum. As the length increases the period increases and the frequency decreases.

2) the period of the pendulum does not depend on the amplitude (size) of the swing - at least to a good approximation for a small swing angle. This is called (isochronicity).

The modern analysis of pendulum motion uses concepts from a branch of physics called classical mechanics, which was formulated by Isaac Newton (1642 - 1726). This uses concepts such as force, acceleration, velocity and gravity to describe the motion. This description eventually includes prescriptions for (approximately) finding the period of the pendulum

The results of this analysis, which can be done exactly when the amplitude of oscillation is small are:

Feature	Importance for Timekeeping
1) the period of oscillation is independent of total mass but can depend on how the mass is distributed.	slight errors in mass when constructing the pendulum will not affect the pendulum's timekeeping (Q What effect?)
2) the period of oscillation increases as the length of the pendulum increases, or the mass is moved further from the pivot.	the period can be adjusted so that it is suitable for counting specific units of time by adjusting the length (Q What effect?)
3) the period of the pendulum is approximately independent of the amplitude of oscillation (if the amplitude is small) 	the pendulum will count time correctly even if the way it is set into motion varies or its amplitude dies as it oscillates.

The exact physics analysis results in a relatively simple formula for the period of a simple pendulum.

$$\text{Period of a simple pendulum for small amplitudes} = 2 \times \pi \times \sqrt{\frac{\text{length}}{9.8\ m/s^2}}$$

Physics experiments routinely verify this with approximate modifications for larger amplitudes

Historical analysis of pendulum behavior.

Early pioneers in the study of pendulum behavior were Oresme (14th century) and Leonardo da Vinci (15th century). They did not carry out any type of quantitative analysis of the motion. The pendulum was first studied in a modern scientific way by Galileo Galilei (1564-1642). He established:

1) the period of the pendulum does not depend on the amplitude of its swing.
2) the period of the pendulum increases as the length increases.

The conventional description of his experiments is that he used his pulse to time the pendulum swings. However, he had used clepsydrae in to do the timing in other experiments.

Galileo did use the pendulum to construct a device to measure a human pulse - this was called a pulsilogium. The fundamental realization was that the timekeeping could be done by a pendulum rather than a pulse.