Physics 140 – Fall 2007
lecture #25: 4 Dec

Ch 15 topics: Sec 1-4, 6-8

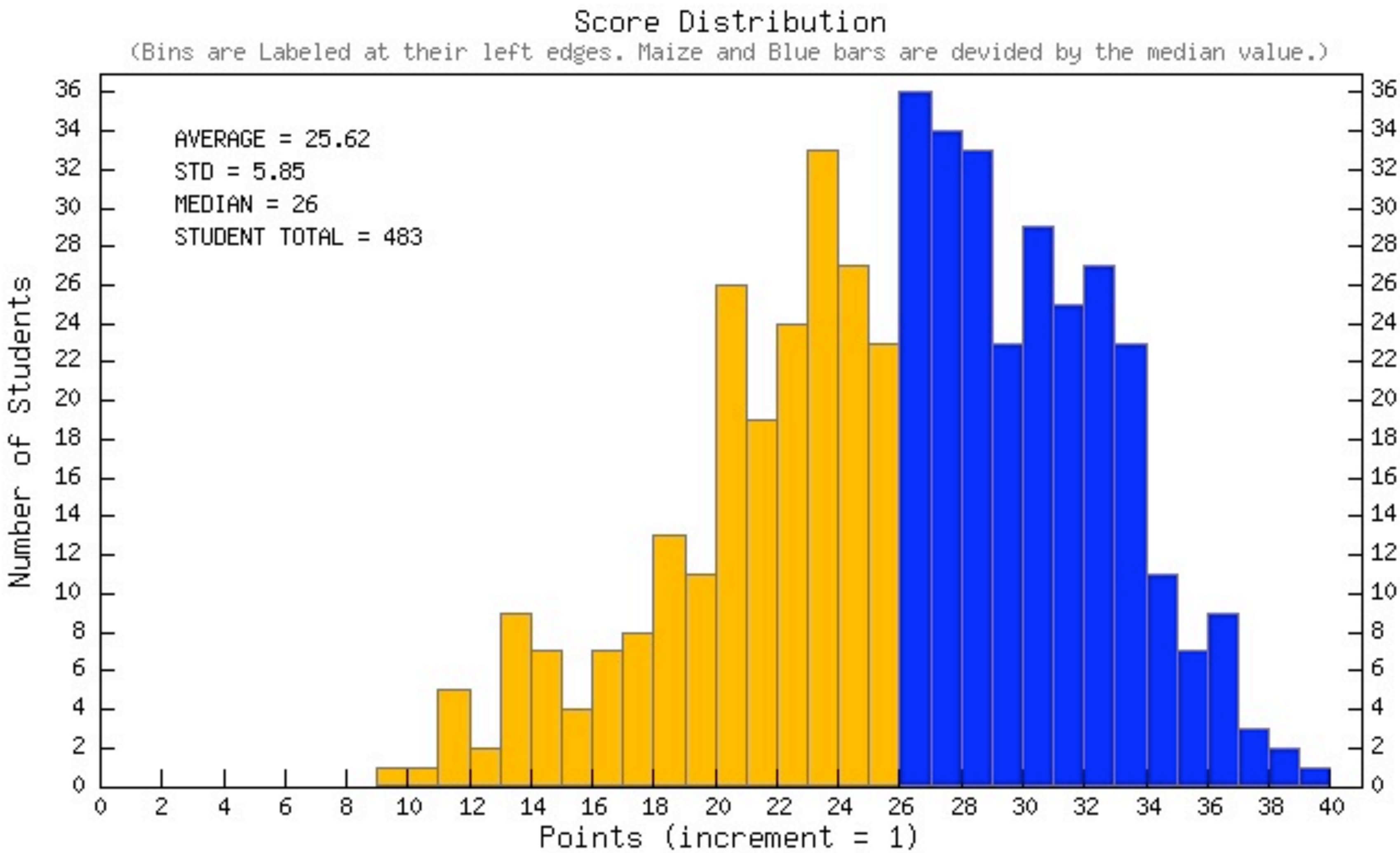
- mechanical waves
  - transverse
  - longitudinal
- wave speed (taut string)
- wave superposition (addition)
- standing waves, nodes, anti-nodes

Note:

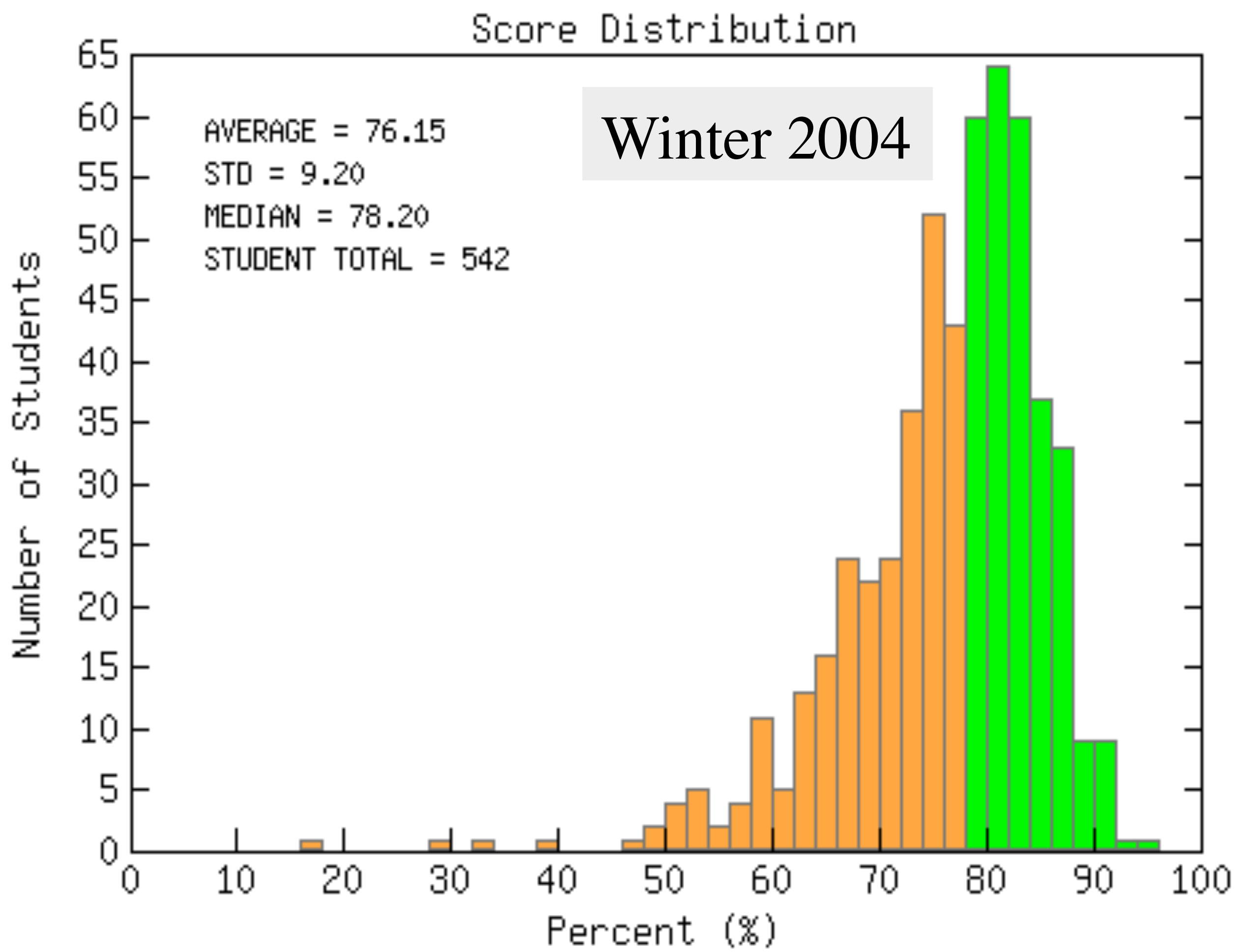
1) Guest lecturer this Thursday
   Prof. Dragan Huterer
2) No Help Room Office hours this Wed

Cosmic Cartography meeting in Chicago

midterm 3 score distribution



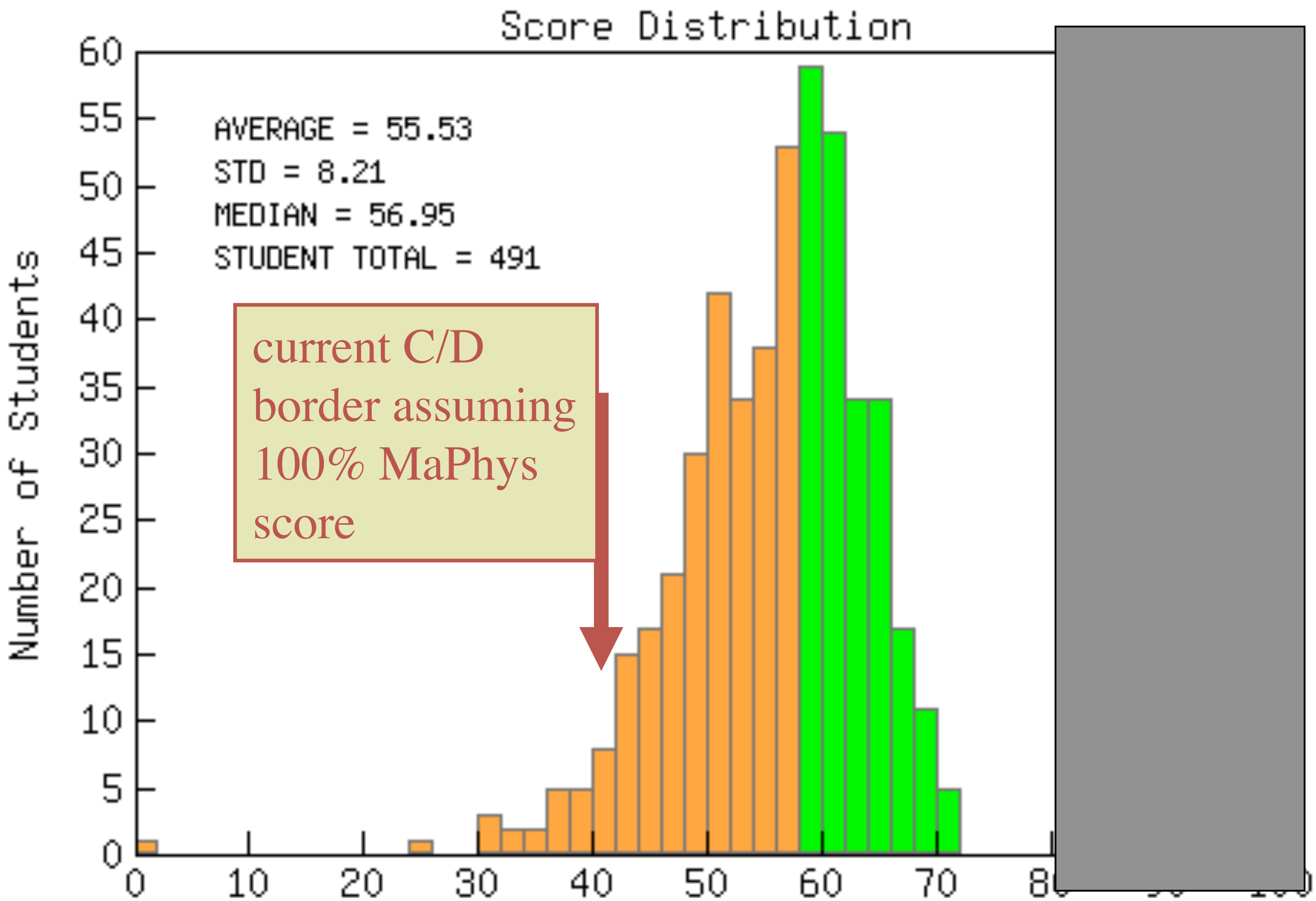
Typical final overall score dist'n



Score	Letter grade
85-100%	A
75-85%	B
60-75%	C
45-60%	D
<45%	E

Current score dist’n (out of 80% total)

NOTE: This is missing 20% from MaPhys



(on Sams) Scores to date / All Scores

Final exam is **next Friday, 14 Dec, 7:30–9:30pm**

Alternate: 4:00–6:00pm

- bring: up to **<u>four</u>** 3x5 notecards or one 8.5x11 sheet, calculator, #2 pencils, student ID
- **22 questions**
  - 12 on Ch 13–16
  - 10 on Ch 1–12
- practice final exam on CTools site

<u>Next Tuesday:</u> Final Review (in lecture)

Final exam Locations
Friday, 14 Dec, 7:30–9:30pm

Waves

All waves are ***oscillating disturbances*** that move through space over time. Some types of waves (electromagnetic and quantum waves of matter) can travel in a vacuum. Others, known as ***mechanical waves,*** (water waves, sound) *require a medium* that supports the disturbance.

Mechanical Waves

Mechanical waves produce a ***displacement*** of particles within a medium that both

- **oscillates in time at any location** and
- **oscillates through space at any time.**

There are two basic types of mechanical waves:

1. **longitudinal:** The particle displacement is parallel to the direction of the traveling wave.

   sound is a longitudinal wave

2. **transverse:** The particle displacement is perpendicular to the direction of the traveling wave.

   ***waves* on a pond's surface** are transverse waves

Describing wave motion

A ***traveling wave*** causes a displacement in the medium that

repeats in time over a period T and
repeats in space over a wavelength λ.

The general mathematical form for such a disturbance is

$$y(x,t) = h(kx \pm \omega t)$$

where *h*(*z*) is a function that specifies the wave amplitude and shape.

A **+** sign represents a wave moving the in **–*x*** direction
while a **–** sign represents a wave moving the in **+*x*** direction.

The ***angular wavenumber k*** is defined by the wavelength $k=2\pi/\lambda$.

Sinusoidal waves

A simple and useful example is a sinusoidal wave

$$y(x,t) = A\cos(kx \pm \omega t)$$

which describes SIMPLE HARMONIC MOTION IN BOTH SPACE AND TIME. Such a wave is characterized by

A : **maximum displacement amplitude** (or, simply, the *amplitude*)

ω : **angular frequency** $(\omega = 2\pi/T = 2\pi f)$

k : **angular wavenumber** $(k = 2\pi/\lambda)$

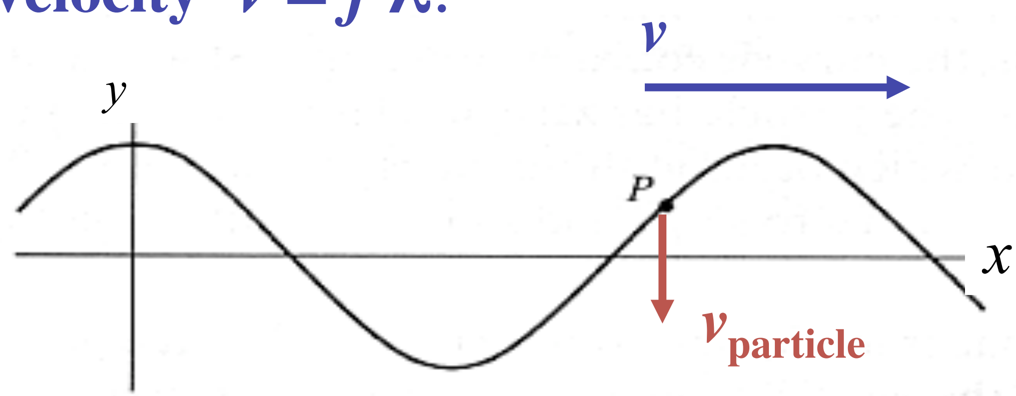
The combination $kx - \omega t$ defines the ***phase*** of a rightward traveling wave. A point of fixed phase (e.g. a "peak" or a "trough") will move in the +x direction with a velocity given by

$$v = \omega/k, \text{ the } \underline{\textbf{wave speed}}.$$

Alternate forms for the wave speed are $v = f\lambda = \lambda/T$.

Wave velocity *vs*. particle velocity

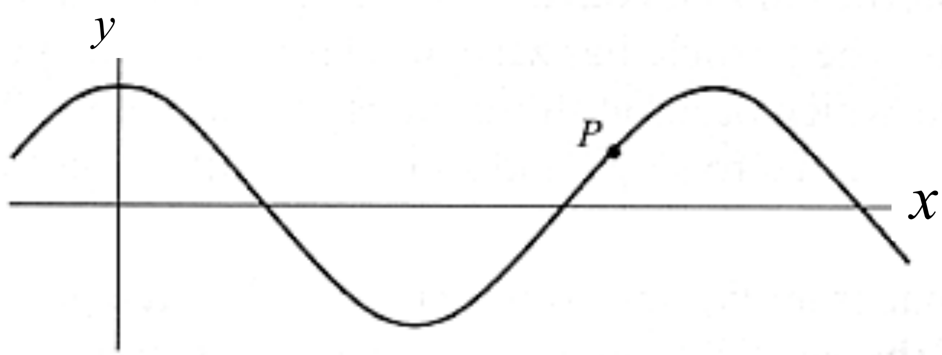
The wave disturbance travels through the medium with a speed given by the **wave velocity** $v = f\lambda$.



At the same time, a small piece (a particle) of the medium oscillates about its equilibrium location, implying a

maximum particle velocity $v_{\text{particle}} = \omega A$.

The direction of the particle velocity is either perpendicular to (for transverse waves, as shown above) or parallel to (for longitudinal waves) the direction of the wave velocity.



A wave traveling along a string (shown above) takes the form

$$y(x,t) = A\ \cos\,(2x + 4t)$$

with x in meters and t in seconds. Imagine following the motion of the point of constant phase, P, as the wave evolves. After 2s elapse, where will point P be located?

1. at the same x position
2. 2m to the right of its current position
3. 2m to the left of its current position
4. 4m to the right of its current position
5. 4m to the left of its current position

Speed of waves on a taut string

A string with mass per unit length μ stretched under tension F (we use F here to avoid confusion with the period T) supports transverse waves that travel with speed

$$v = \sqrt{\frac{F}{\mu}}$$

Waves travel faster when the tension is higher or when the medium is less dense.

This expression implies an energy equation for a small length of string Δx of the form

$$(\mu \Delta x) v^2 = F \Delta x$$

meaning tension supplies the work needed to support wave motion in the string.

Superposition (adding) of waves

When two traveling waves $y_1(x,t)$ and $y_2(x,t)$ intersect, their wave displacements add

$$y(x,t) = y_1(x,t) + y_2(x,t)$$

Reflection of waves from a boundary

A wave that travel to a boundary is reflected. Upon reflection, the wave's ***velocity reverses*** and its phase is either

changed by π radians if the boundary is fixed (closed) or
unchanged if the boundary is free (open).

For animated examples of wave superposition and reflection, see
http://www.kettering.edu/~drussell/Demos/superposition/superposition.html

Standing waves

Waves on a string of length L that is fixed between two posts are constrained to have reflecting nodes at each end of the string. The superposition of incident and reflected waves

$$y(x,t) = A\cos(kx - \omega t) - A\cos(kx + \omega t)$$

leads to a particular wave form, termed ***standing waves***, whose behavior has separated space and time components

$$y(x,t) = 2A\sin(kx)\sin(\omega t)$$

Standing waves have locations with zero displacement (at all times)

nodes : locations x at which $y\,(x,t) = 0$,

and also locations with maximum amplitude

anti-nodes : locations x at which $y\,(x,t) = 2A$.

Normal modes

For a taut string tied at both ends (as in any stringed musical instrument), the existence of nodes at at x=0 and x=L requires that ***an integer number of half-wavelengths must fit on the string***.

If the string supports wave velocity v, this condition restricts the frequencies that can be expressed by the string to a discrete set of values

$$f_n = n\,(v/2L) \quad ; \quad n = 1, 2, 3, \ldots$$

termed the *fundamental mode* (n=1)
and *higher harmonics* (n>1).

A string oscillating between two posts exhibits a standing wave pattern with four nodes between the posts. If the tension in the string is decreased by a factor 4 with all else held constant, how many nodes will there be between the posts?

1. two
2. four
3. eight
4. nine

When I hang this slinky by one end and then drop it, what will happen?

1) The bottom end of the slinky will immediately start falling at the same rate as the top.
2) The bottom end of the slinky will rise up, and the two ends will meet in the middle. Then the whole thing will fall to the floor.
3) The bottom end of the slinky will hang suspended momentarily, then start falling.