Ever wondered what percentage of oxygen molecules travel over 341m/s (land speed record)?

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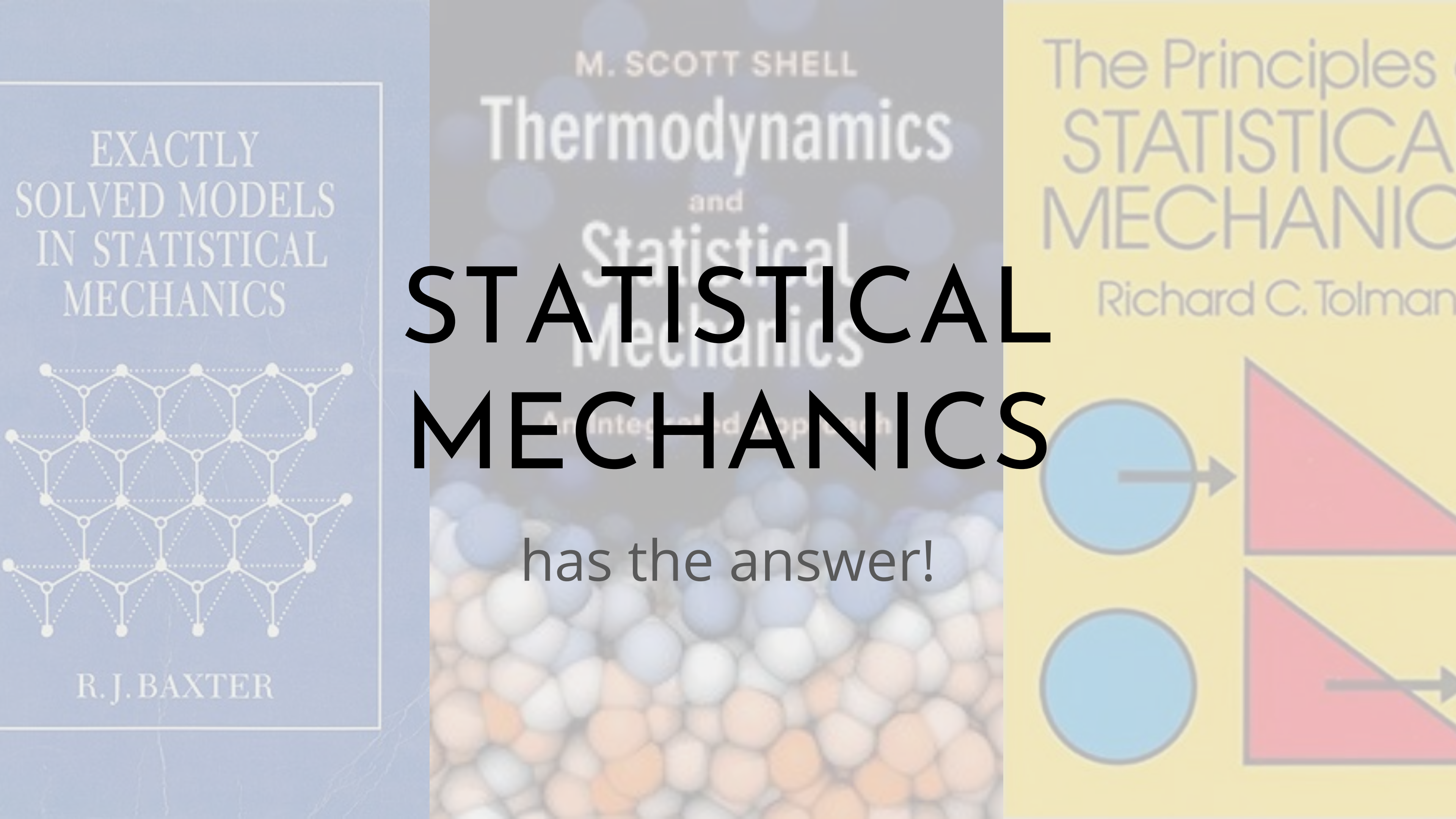
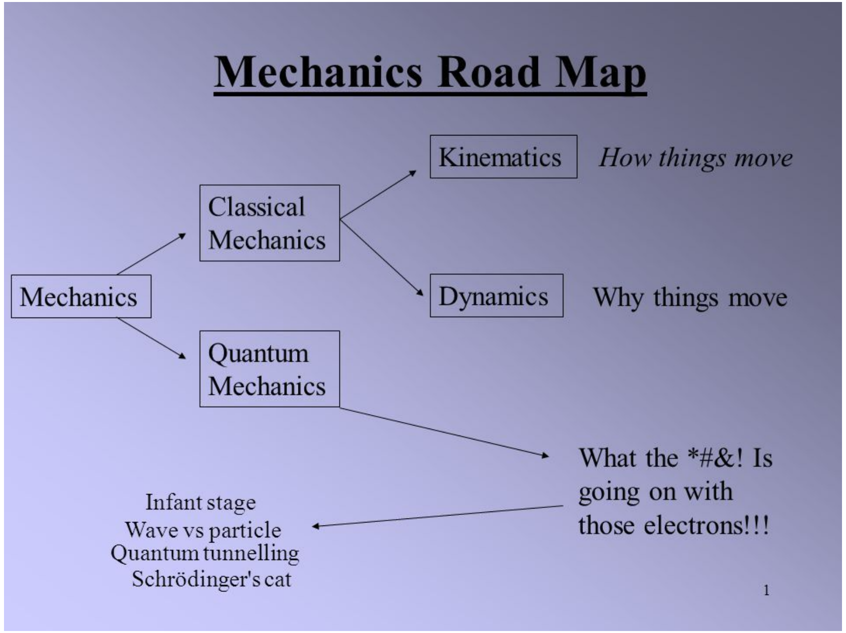
(probably not)


STATISTICAL MECHANICS
has the answer!
EXACTLY SOLVED MODELS IN STATISTICAL MECHANICS
R.J. BAXTER
M. SCOTT SHELL
Thermodynamics and Statistical Mechanics
The Principles
STATISTICA
MECHANIC
Richard C. Tolman

(CLASSICAL) MECHANICS

Mechanics is “a branch of physical science that deals with energy and forces and their effect on bodies” (Merriam Webster)



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(CLASSICAL) MECHANICS

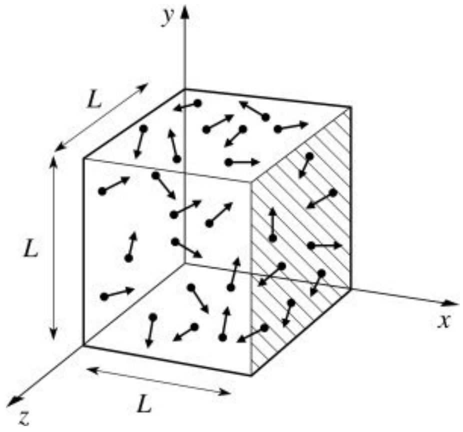
Mechanics is “a branch of physical science that deals with energy and forces and their effect on bodies” (Merriam Webster)

Much of our class focused on mechanics, but on a macroscopic scale

We dealt with experimentally-based models that used rely on the predictable nature of objects

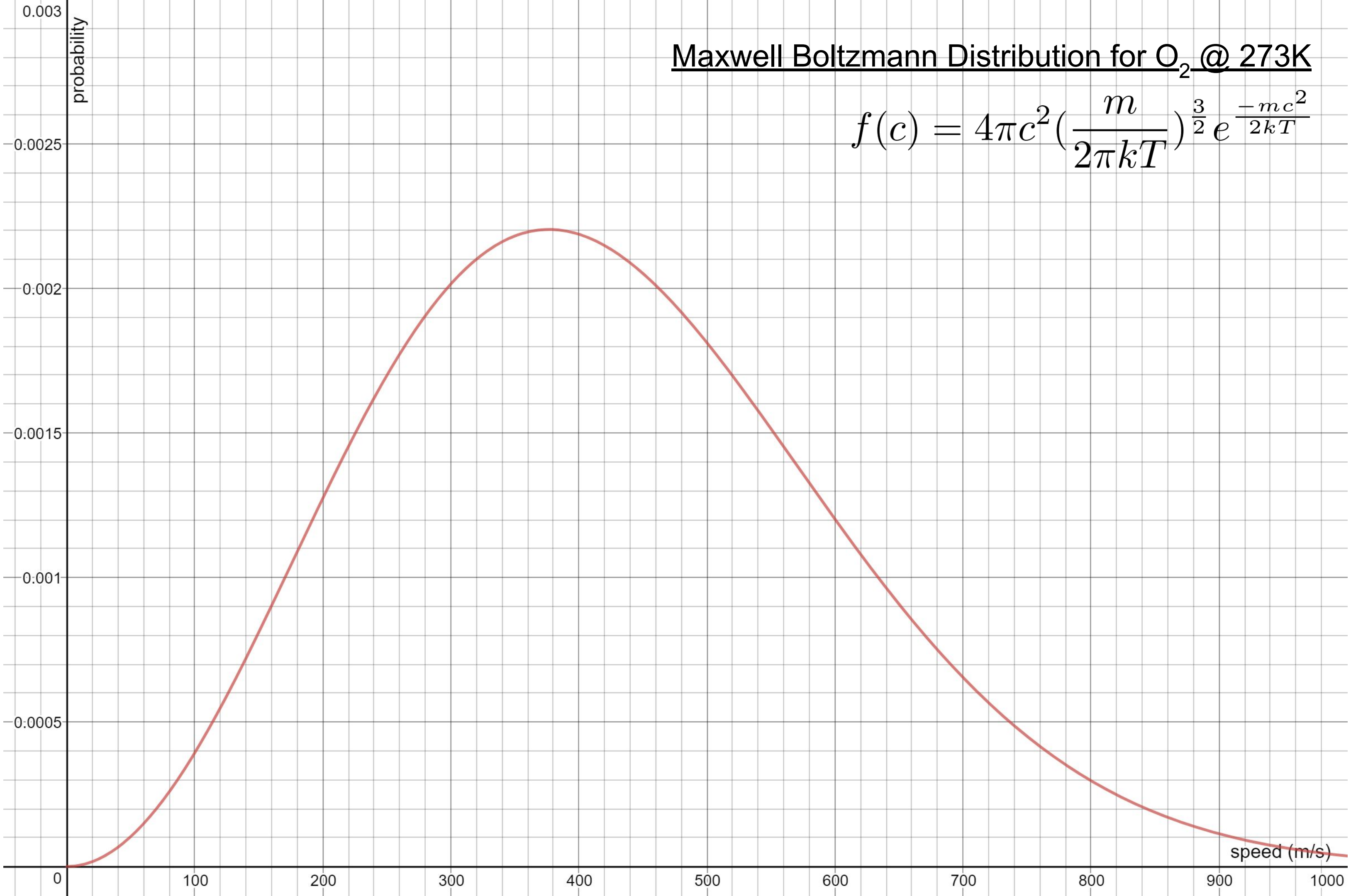
PROBLEMS WITH THIS KIND OF MECHANICS

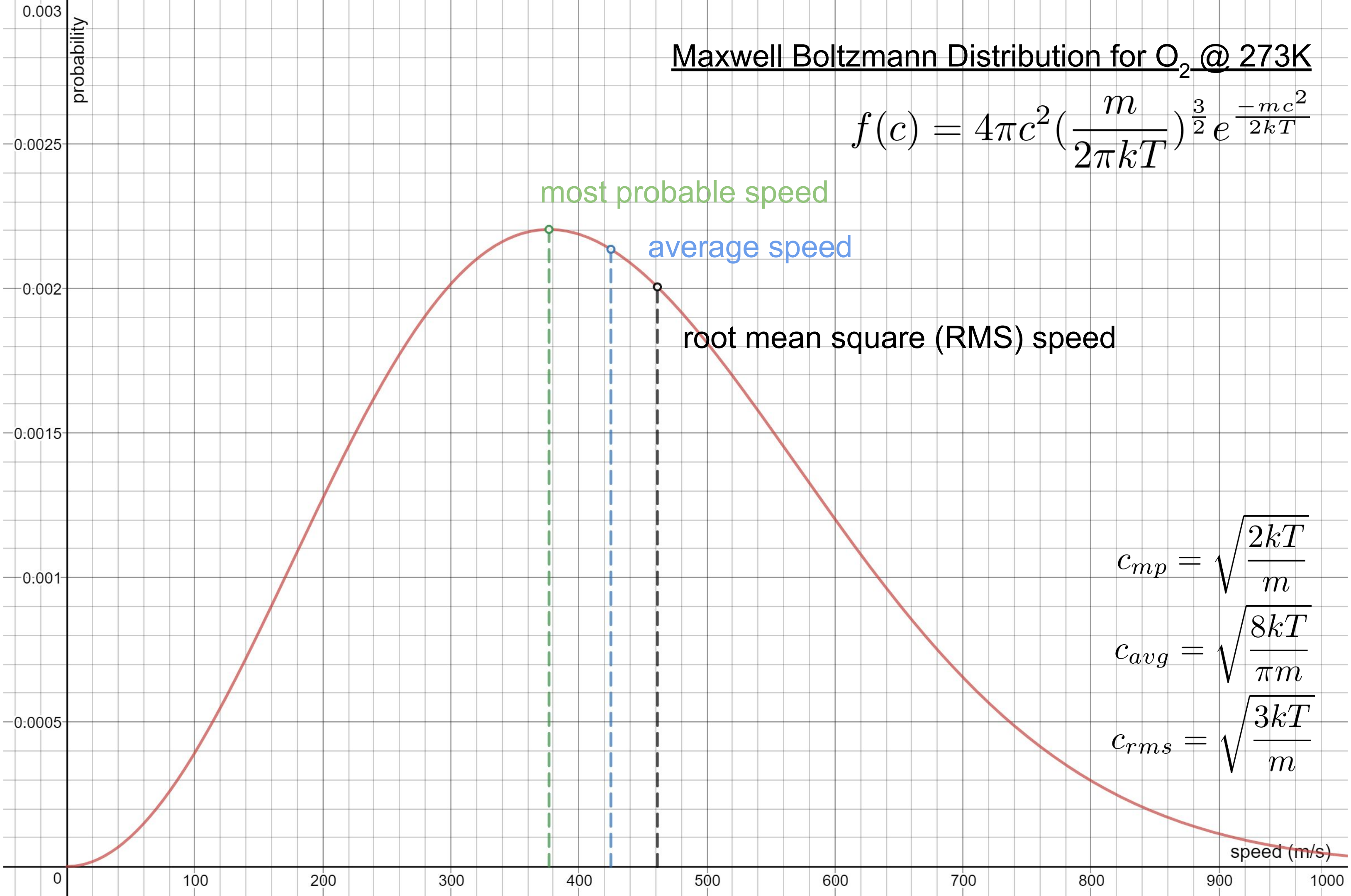
- The objects studied in class were reasonably sized
- The number of objects and variables studied in class were reasonable
- There is always some variation to physical objects, which becomes more apparent at a microscopic level



Let’s bring back this question…

Ever wondered what percentage of oxygen molecules travel over 341m/s (land speed record)?


Maxwell Boltzmann Distribution for O_2 @ 273K
$$f(c) = 4\pi c^2\left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} e^{\frac{-mc^2}{2kT}}$$
probability
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
100
200
300
400
500
600
700
800
900
1000
speed (m/s)



Maxwell Boltzmann Distribution for O_2 @ 273K
$f(c) = 4\pi c^2 (\frac{m}{2\pi kT})^{\frac{3}{2}} e^{\frac{-mc^2}{2kT}}$
most probable speed
average speed
root mean square (RMS) speed
$c_{mp} = \sqrt{\frac{2kT}{m}}$
$c_{avg} = \sqrt{\frac{8kT}{\pi m}}$
$c_{rms} = \sqrt{\frac{3kT}{m}}$
probability
speed (m/s)
0.003
0.0025
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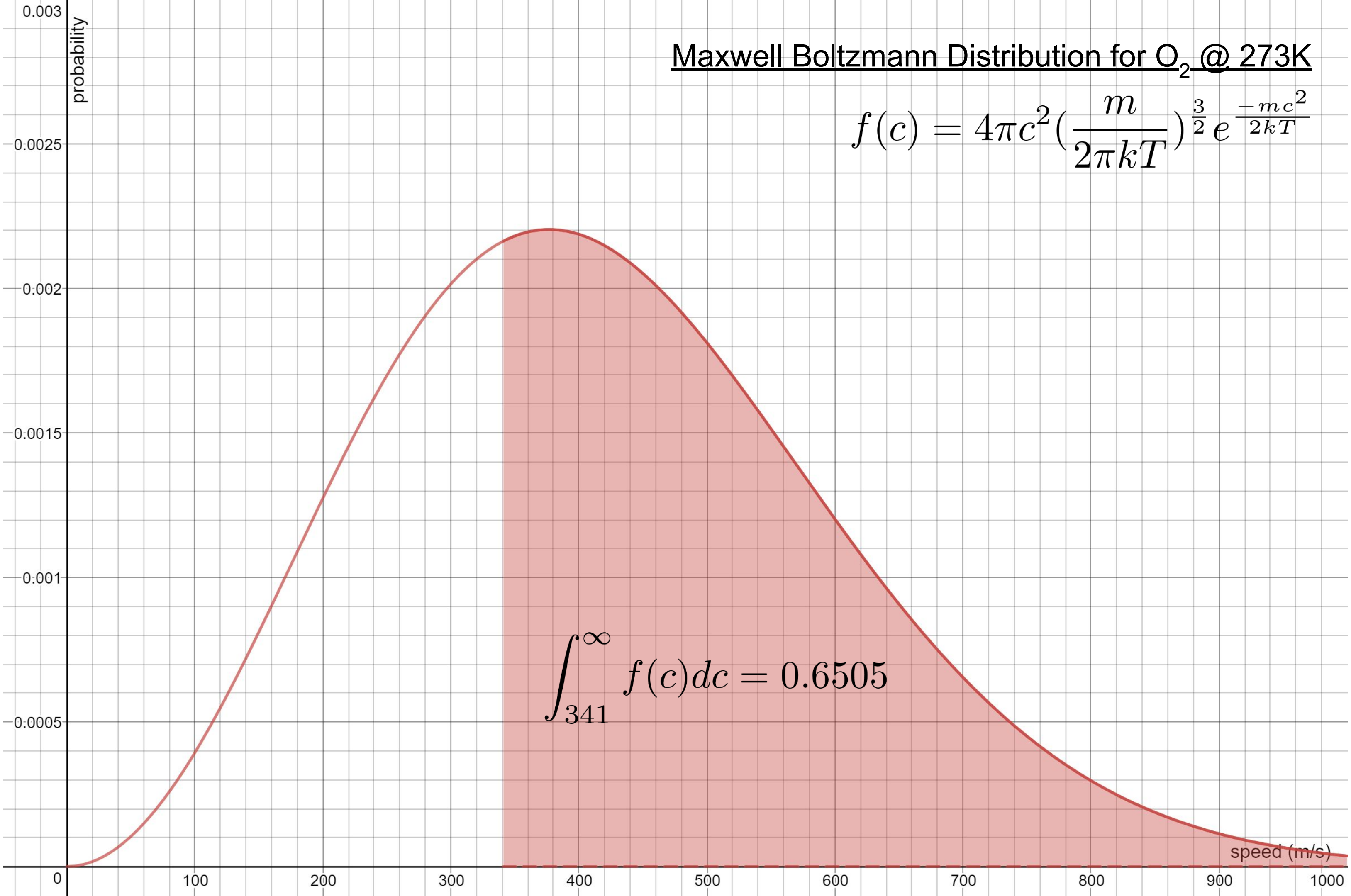

Maxwell Boltzmann Distribution for O_2 @ 273K
$f(c) = 4\pi c^2 (\frac{m}{2\pi kT})^{\frac{3}{2}} e^{\frac{-mc^2}{2kT}}$
$\int_{341}^{\infty} f(c)dc = 0.6505$
probability
speed (m/s)
0.003
0.0025
0.002
0.0015
0.001
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0
100
200
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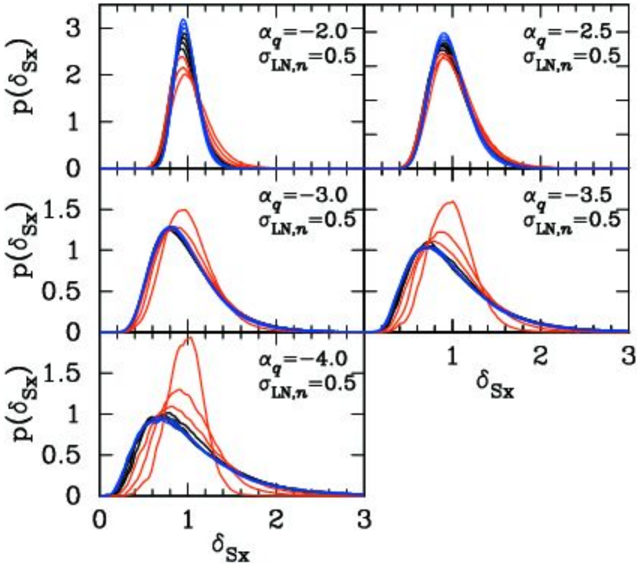
STATISTICS TO THE RESCUE!

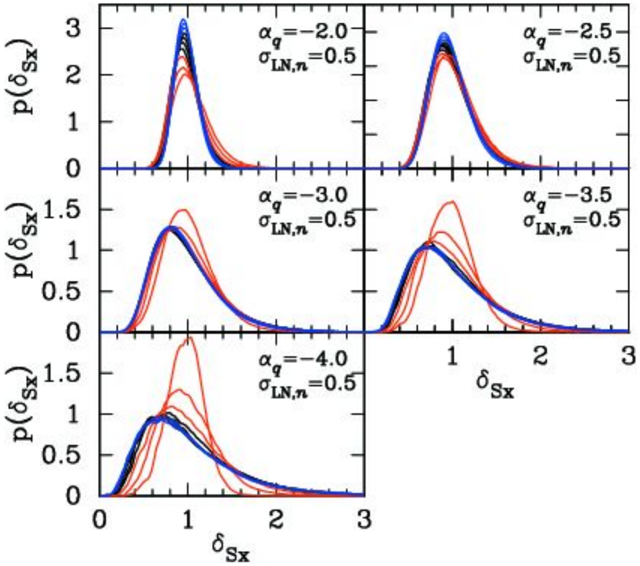
Statistical physics uses probability theory to provide mathematical models to problems with many variables, and can deal with problems in many other fields of science, economics, and the social sciences.



STATISTICS TO THE RESCUE!

Statistical physics uses probability theory to provide mathematical models to problems with many variables, and can deal with problems in many other fields of science, economics, and the social sciences.

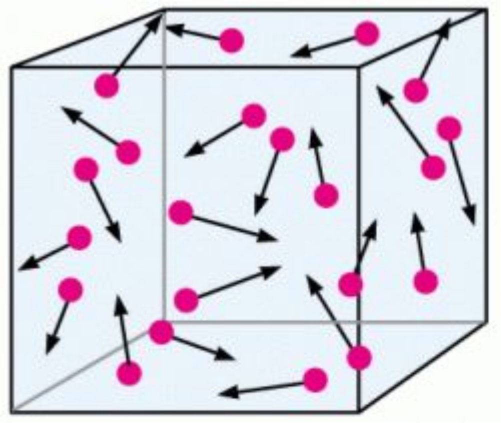
Statistical mechanics (specifically) deals with mechanics, especially in thermodynamics (statistical thermodynamics).



HISTORY

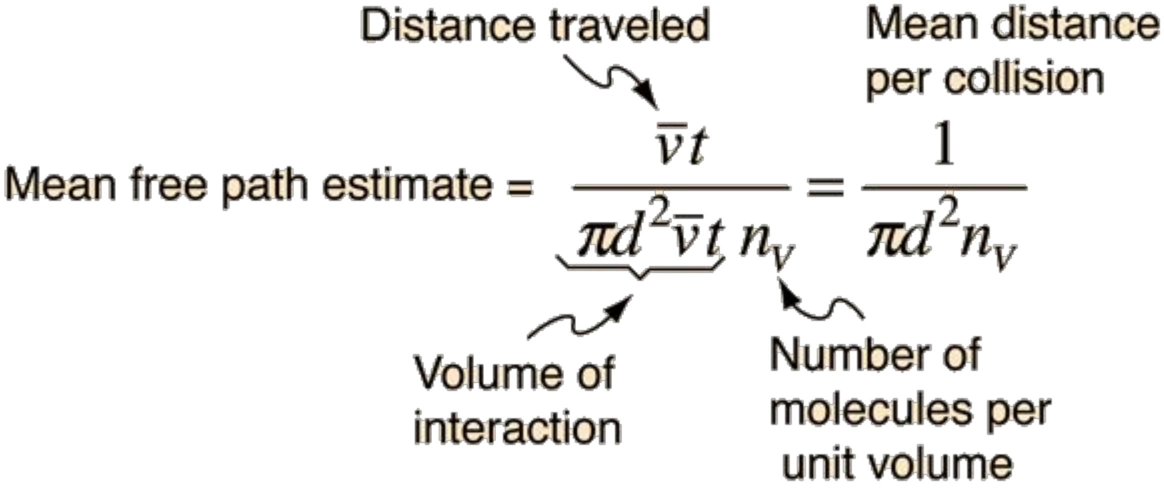
DANIEL BERNOULLI (1700-1782)

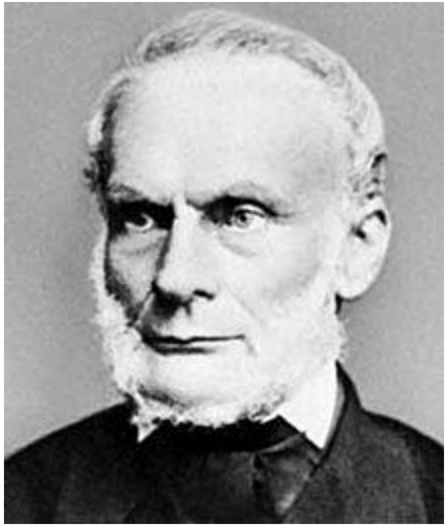
- pioneer of the Kinetic Theory of Gases, the first model that predicted large numbers of particles moving in stochastic motion



RUDOLF CLAUSIUS (1822-1888)

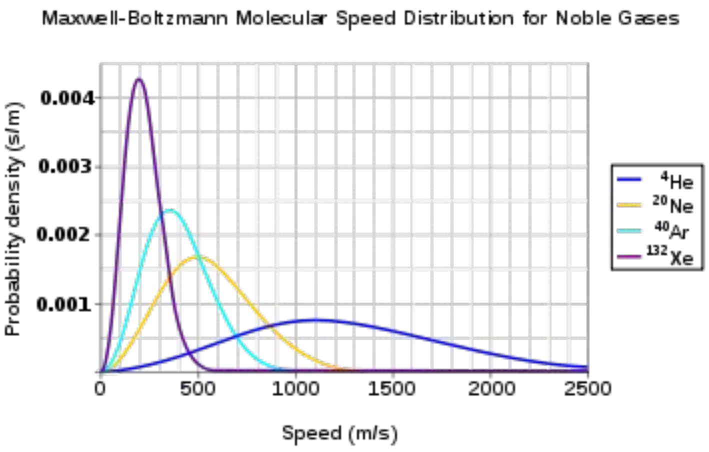
- known for work with thermodynamics
- derived equation for mean free path of a particle, the first basic probabilistic equation

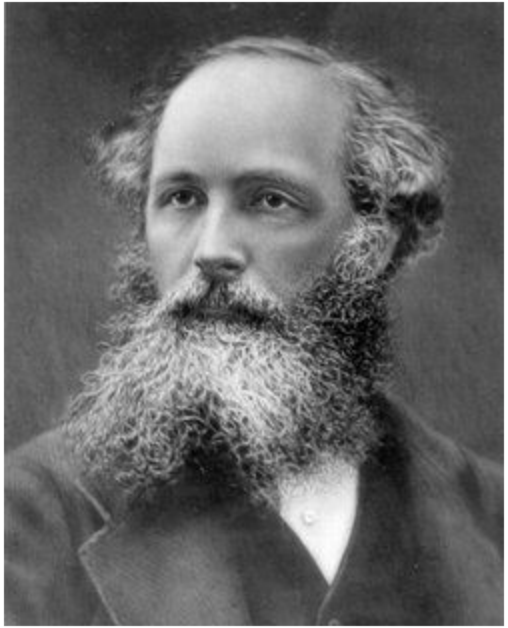




JAMES MAXWELL (1831-1879)

- improved Clausius's equation for MFP
- wrote the first statistical distribution, the Maxwell-Boltzmann distribution for velocity of particles
- discovered root mean square velocity

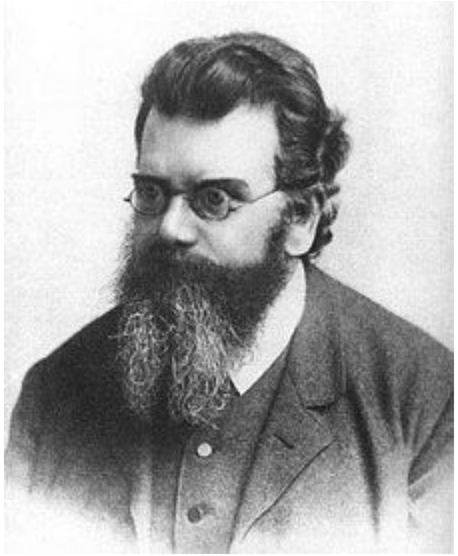




LUDWIG BOLTZMANN (1844-1906)

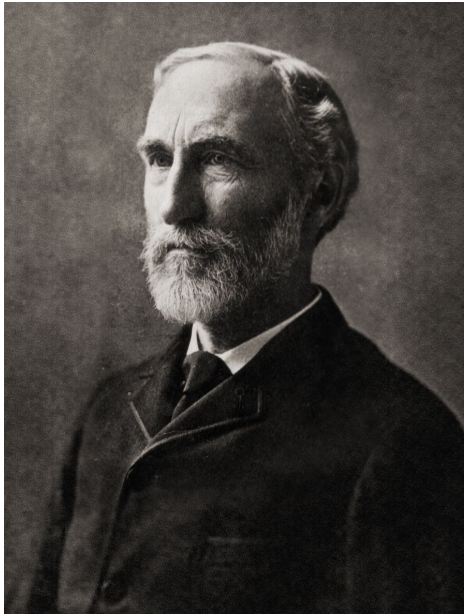
- worked closely with Maxwell
- generalizing Maxwell’s equations to non-equilibrium thermodynamics
- famous H-theorem “proof” for the Second Law of Thermodynamics

$$H(t) = \int_0^\infty f(E,t)\left(\ln \frac{f(E,t)}{\sqrt{E}} - 1\right) dE.$$



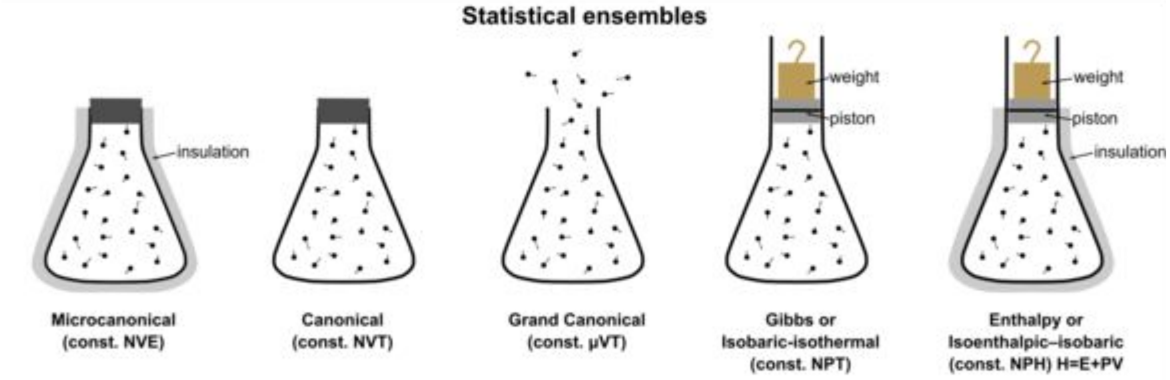
JOSIAH GIBBS (1839-1903)

- introduced the statistical ensemble that generalized Boltzmann’s work to all mechanical systems (not just thermodynamics)



THE STATISTICAL ENSEMBLE

- five main classes of statistical ensemble
- each has its own mathematical model, defined by what is kept constant and what is variable



THE CANONICAL ENSEMBLE (NVT)

- particles (N), volume (V), and temperature (T) constant
- energy can be freely exchanged with a large heat reservoir
- generalized form of a Boltzmann distribution

$$P = e^{\frac{F-E}{kT}}$$

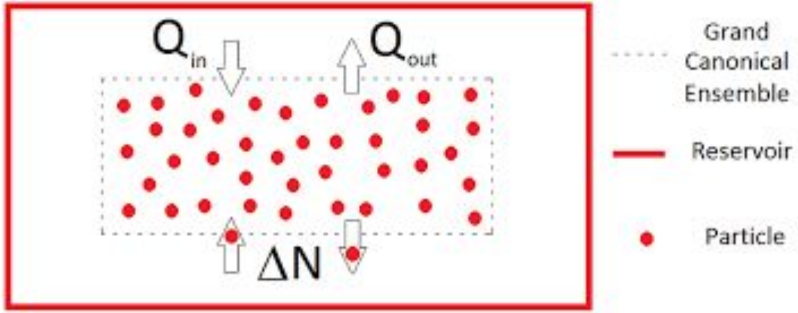
$$F(N, V, T)$$

$$\langle p \rangle = -\frac{\partial F}{\partial V}$$

$$S = k\langle logP \rangle = \frac{\partial F}{\partial T}$$

$$d\langle E \rangle = TdS - \langle p \rangle dV$$

$$\langle E^2 \rangle - \langle E \rangle^2 = kT^2 \frac{\partial \langle E \rangle}{\partial T}$$



EXAMPLES IN THERMODYNAMICS

Equilibrium:

- show the properties of a material

Nonequilibrium:

- internal heat transfer in a material
- friction and energy dissipation
- electric currents created by a voltage imbalance
- spontaneous chemical reactions

EXAMPLES OUTSIDE THERMODYNAMICS

- ensemble weather forecasting
- plotting gravitational orbits
- economic theory
- evolution and dynamics of neural networks

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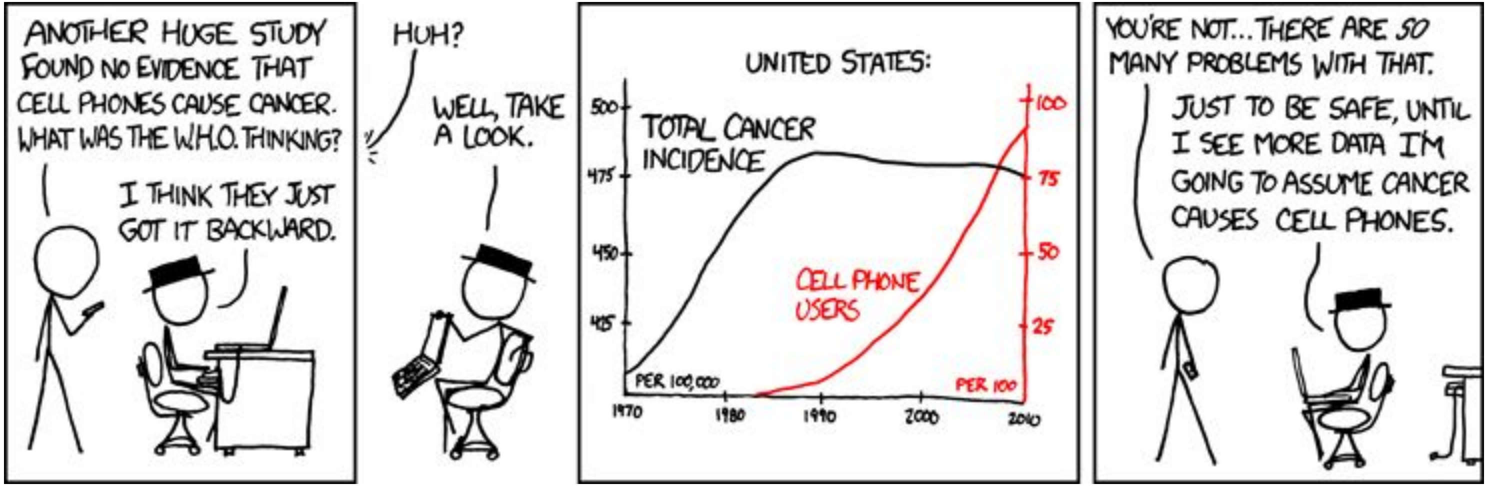
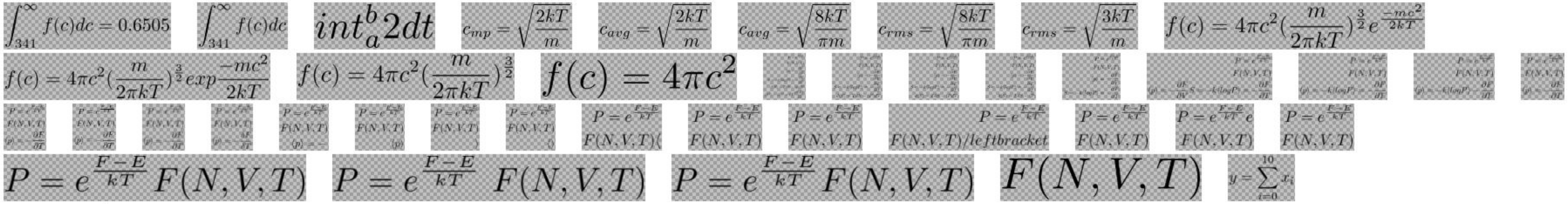
source: xkcd 925: “Cell Phones”

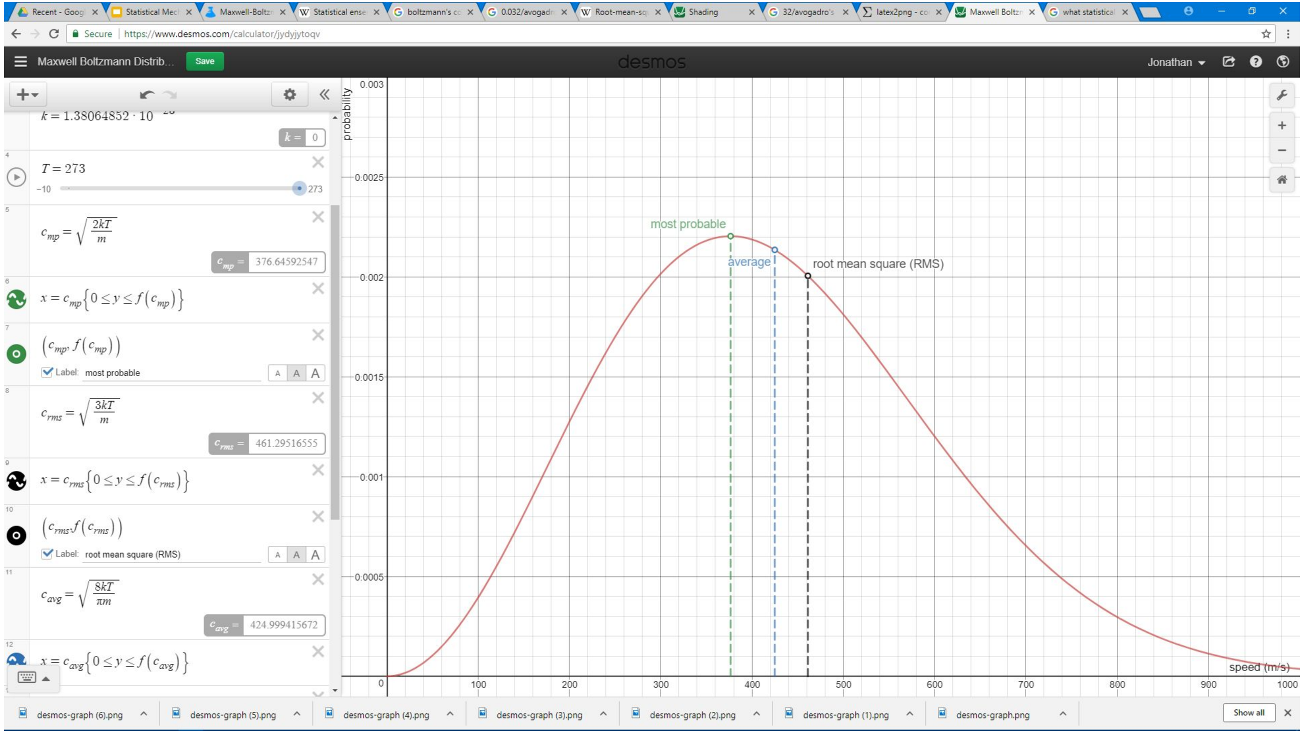


TL;DR:

statistics gets a lot more mathy than stat. class

THANKS FOR WATCHING! ~ jonlam





(also LaTex and Desmos are cool)