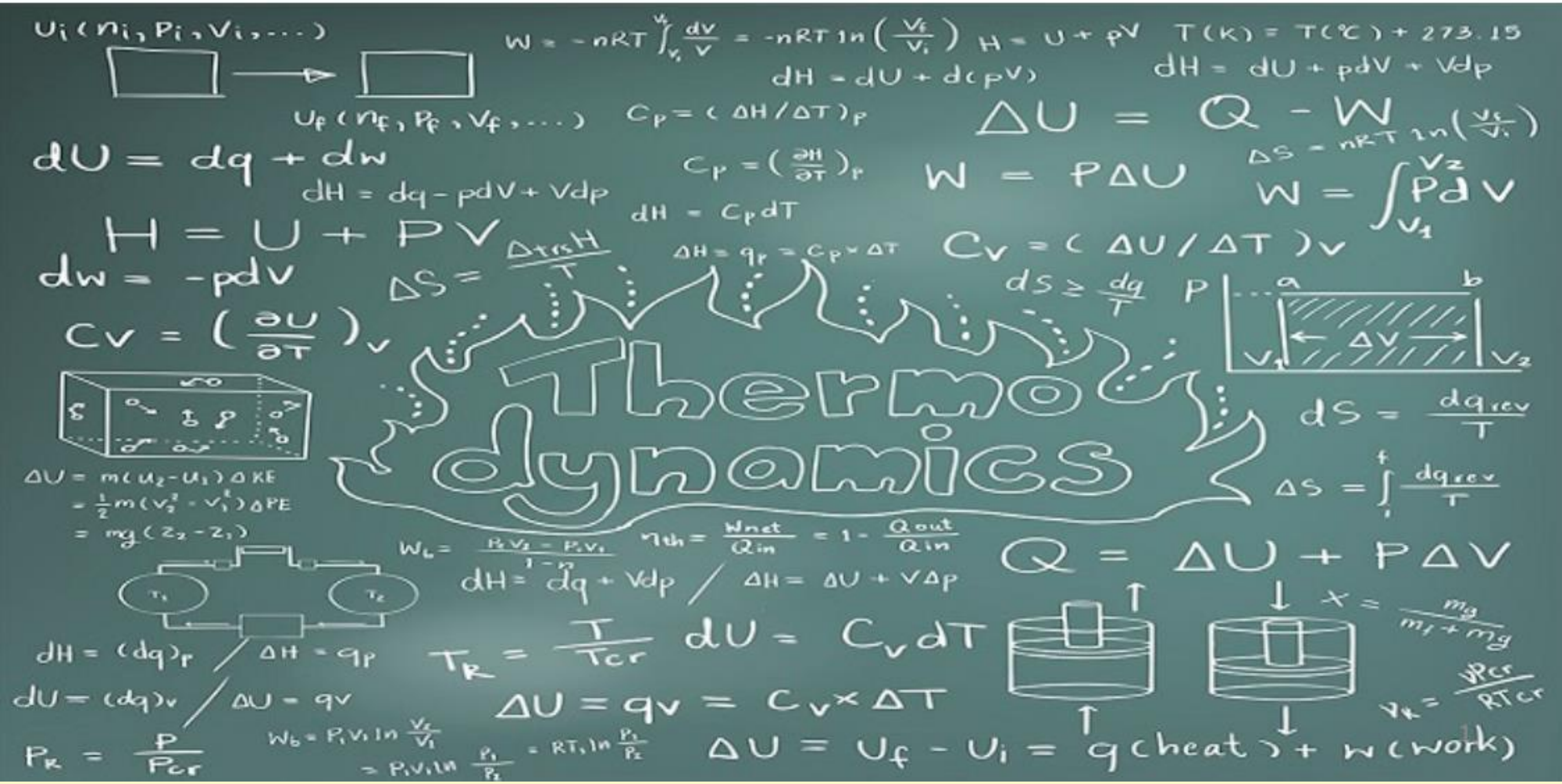
PHYS1013
Energy and Matter



The first assessed mastering physics problem
is due on Sunday (by midnight)

Workshops begin this week

Week 1 Key Concepts

- **Pressure** is force per unit area ($P = F/A$).

Gases

- **Equation of state for ideal gases:** $PV = NkT$, $P = nkT$, $PV = n_m RT$ where $N = N_A n_m$
- **Transport Laws:**
  Diffusion is caused by density gradient: $\frac{dm}{dt} = -DA\frac{d\rho}{dx}$
  Thermal Conductivity is caused by temeprature gradients: $\frac{dQ}{dt} = -KA\frac{dT}{dx}$
  Viscosity is caused by a velocity gradient: $F_x = -\eta A\frac{dv_x}{dy}$

Liquids

- **Archimedes' principle:** there is an upwards force on an object from the pressure in the water which is precisely equal to the weight of the water displaced (because that displaced water used to be in equilibrium).
- The pressure at a depth d in water is given by $P = \rho dg$ where ρ is the density of water 1000 kg m^{-3}, and g =9.81 m s^{-2}

Solids

- **Young's Modulus**: stress $\propto$ strain $\frac{F}{A} = Y\frac{\delta l}{l}$
- **Bulk Modulus**: contraction under equal surrounding pressure $\Delta P = -B\frac{\Delta V}{V}$
- **Thermal Expansivity**: $\frac{\Delta V}{V} = \alpha\Delta T$

Problem sheet 1 is now available for the workshops

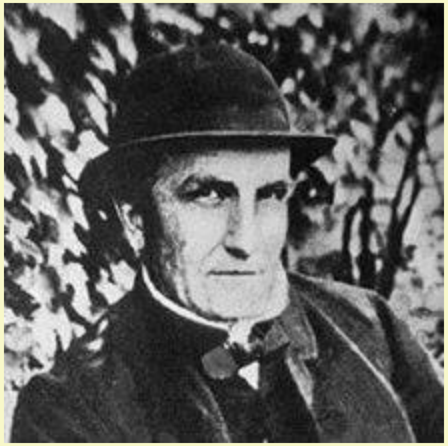
- **Ideal gases**: large number of molecules; they are small; positions and velocities evenly distributed; Newton's laws; eleastic collisions with each other and walls.
- $P = \frac{1}{3} m n \bar{v^2}$
- $PV = \frac{1}{3} m N \bar{v^2} = \frac{2}{3} U$ (where U is the internal (kinetic) energy)

Daniel Bernoulli FRS (1700 –1782) was a Swiss mathematician and physicist in the Bernoulli family from Basel. He is particularly remembered for his applications of mathematics to mechanics, especially fluid mechanics, and for his pioneering work in probability and statistics. His name is commemorated in the Bernoulli's principle, a particular example of the conservation of energy, which describes the mathematics of the mechanism underlying the operation of two important technologies of the 20th century: the carburetor and the airplane wing.

In 1738 Daniel Bernoulli published *Hydrodynamica*, which laid the basis for the kinetic theory of gases. In this work, Bernoulli posited the argument, that gases consist of great numbers of molecules moving in all directions, that their impact on a surface causes the pressure of the gas, and that their average kinetic energy determines the temperature of the gas. The theory was not immediately accepted, in part because conservation of energy had not yet been established, and it was not obvious to physicists how the collisions between molecules could be perfectly elastic.

At the beginning of the 20th century, however, atoms were considered by many physicists to be purely hypothetical constructs, rather than real objects. An important turning point was Albert Einstein's (1905)[13] and Marian Smoluchowski's (1906)[14] papers on Brownian motion, which succeeded in making certain accurate quantitative predictions based on the kinetic theory.

John James Waterston (1811 -1883) was a Scottish physicist and a neglected pioneer of the kinetic theory of gases.



Waterston's father, George, was an Edinburgh sealing wax manufacturer and stationer. At age nineteen, Waterston published a paper proposing a mechanical explanation of gravitation, accounting for *action at a distance* in terms of colliding particles and discussing interactions between linear and rotational motion that would play a part in his later kinetic theory.

Waterston moved to London at age twenty-one, where he worked as a railroad surveyor, becoming an associate of the Institution of Civil Engineers and publishing a paper on a graphical method for planning earthworks. Beaufort, in 1839, supported Waterston for the post of naval instructor for cadets of the East India Company in Bombay. The posting worked well for Waterston who was able to pursue his reading and research at the library of Grant College.

While in India, he first developed his kinetic theory, independently of earlier and equally neglected partial accounts by Daniel Bernoulli and John Herapath. He published it, at his own expense, in his book Thoughts on the Mental Functions (1843). He correctly derived all the consequences of the premise. The publication made little impact, perhaps because of the title. He submitted his theory, under Beaufort's sponsorship, to the Royal Society in 1845 but was rejected. Referee Sir John William Lubbock wrote The paper is nothing but nonsense.

The theory gained acceptance only when it was proposed by Rudolf Clausius and James Clerk Maxwell in the 1850s by which time Waterston's contribution had been forgotten. Clausius and Maxwell proposed equipartition of energy.

Joule’s Law

The internal energy of a gas depends only on its temperature, not pressure or volume - U(T)

Wikipedia: James Prescott Joule FRS FRSE (1818 – 1889) was an English physicist, mathematician and brewer, born in Salford, Lancashire. Joule studied the nature of heat, and discovered its relationship to mechanical work (see energy). This led to the law of conservation of energy, which in turn led to the development of the first law of thermodynamics. The SI derived unit of energy, the joule, is named after him.

Specific Heat Capacities vs Predictions

Monatomic	He	Ne	Ar	Xe
C (experiment)	12.5	12.5	12.5	12.5
C (predicted)	12.5	12.5	12.5	12.5
Diatomic	H_2	N_2	O_2	I_2
C (experiment)	20.5	20.8	21.1	28.6
C (predicted)	29.1	29.1	29.1	29.1
Triatomic	CO_2	H_2O	O_3	NO_2
C (experiment)	28.8	25.3	29.9	29.6
C (predicted)	54.0	58.2	58.2	58.2
Solids	Cu	Al	Zn	C (diamond)
C (experiment)	24.5	24.3	25.1	6.1
C (predicted)	24.9	24.9	24.9	24.9

Table 2.1 Experimental and theoretical molar specific heat capacities for different substances. Units $\mathrm{J\,K^{-1}\,mole^{-1}}$.

Ludwig Eduard Boltzmann (1844 1906) was an Austrian physicist and philosopher. His greatest achievements were the development of statistical mechanics, and the statistical explanation of the second law of thermodynamics. In 1877 he provided the current definition of entropy, interpreted as a measure of statistical disorder of a system.[2] Max Planck named the constant k_B the Boltzmann constant.[3]

Boltzmann was born in Erdberg, a suburb of Vienna. His father, Ludwig Georg Boltzmann, was a revenue official. His grandfather, who had moved to Vienna from Berlin, was a clock manufacturer, and Boltzmann's mother, Katharina Pauernfeind, was originally from Salzburg. He received his primary education at the home of his parents.[5] Boltzmann attended high school in Linz, Upper Austria. When Boltzmann was 15, his father died.[6]

Starting in 1863, Boltzmann studied mathematics and physics at the University of Vienna. He received his doctorate in 1866 and his venia legendi in 1869. Boltzmann worked closely with Josef Stefan, director of the institute of physics. It was Stefan who introduced Boltzmann to Maxwell's work

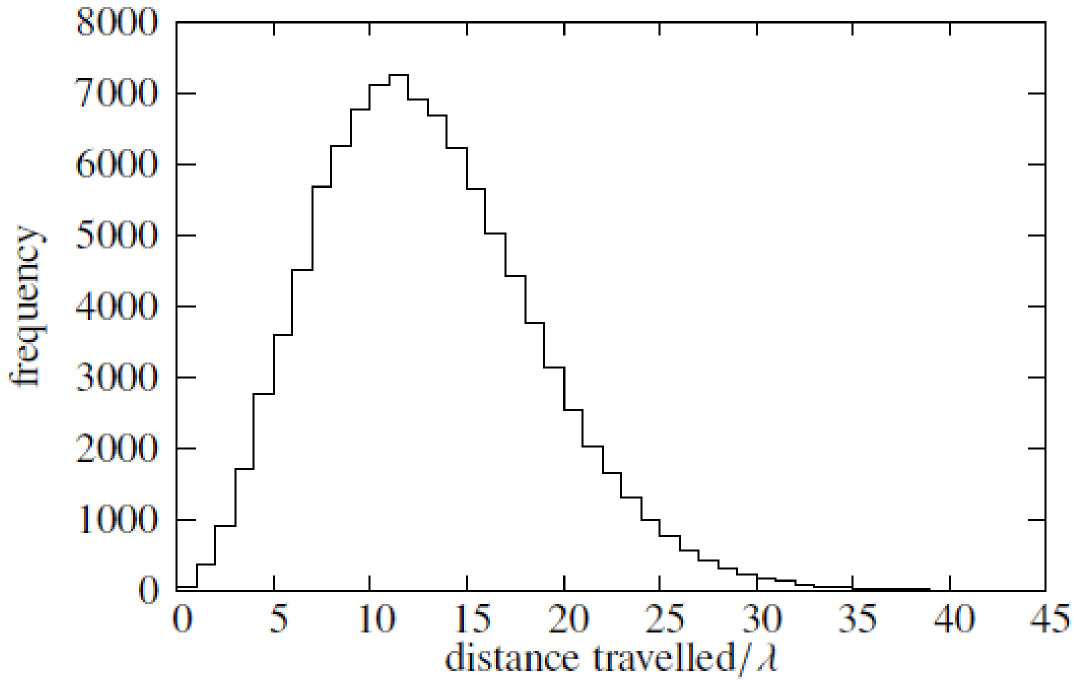


Figure 3.4 Frequency distribution of the distance travelled in 100 000 random walks, each of 100 steps, with the step-lengths themselves distributed according to an exponential distribution with mean λ. The mean distance travelled is 12.99λ, while the rms distance is 14.15λ and the maximum is 44.30λ.