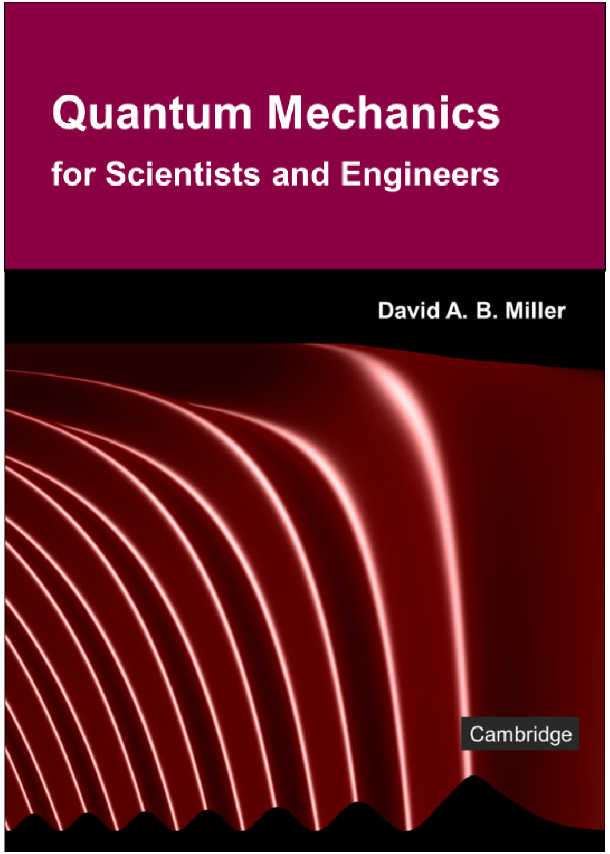
1 Introduction to quantum mechanics

Slides: Lecture 1a Introduction to quantum mechanics

Text reference: Quantum Mechanics for Scientists and Engineers

Section 1.1

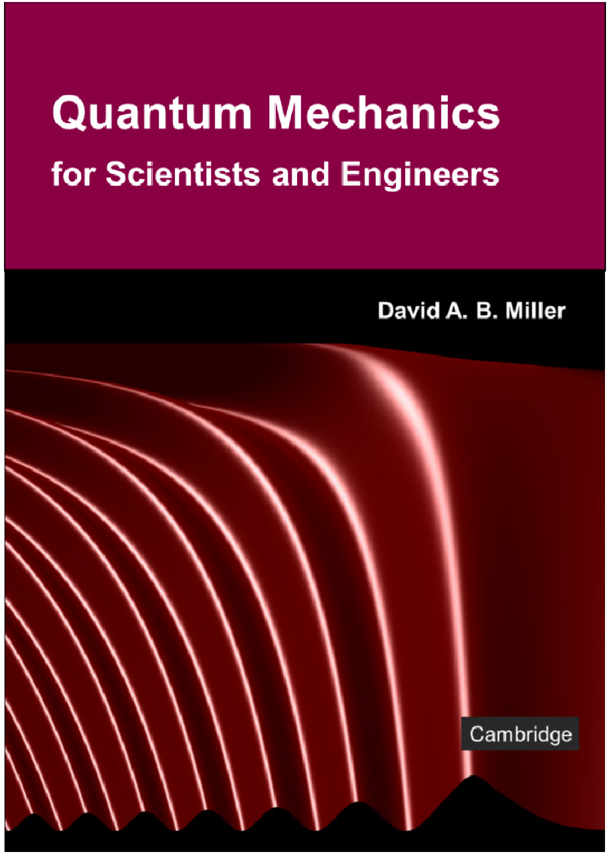


1 Introduction to quantum mechanics

Slides: Lecture 1b Light

Text reference: Quantum Mechanics for Scientists and Engineers

Section 1.1



Introduction to quantum mechanics

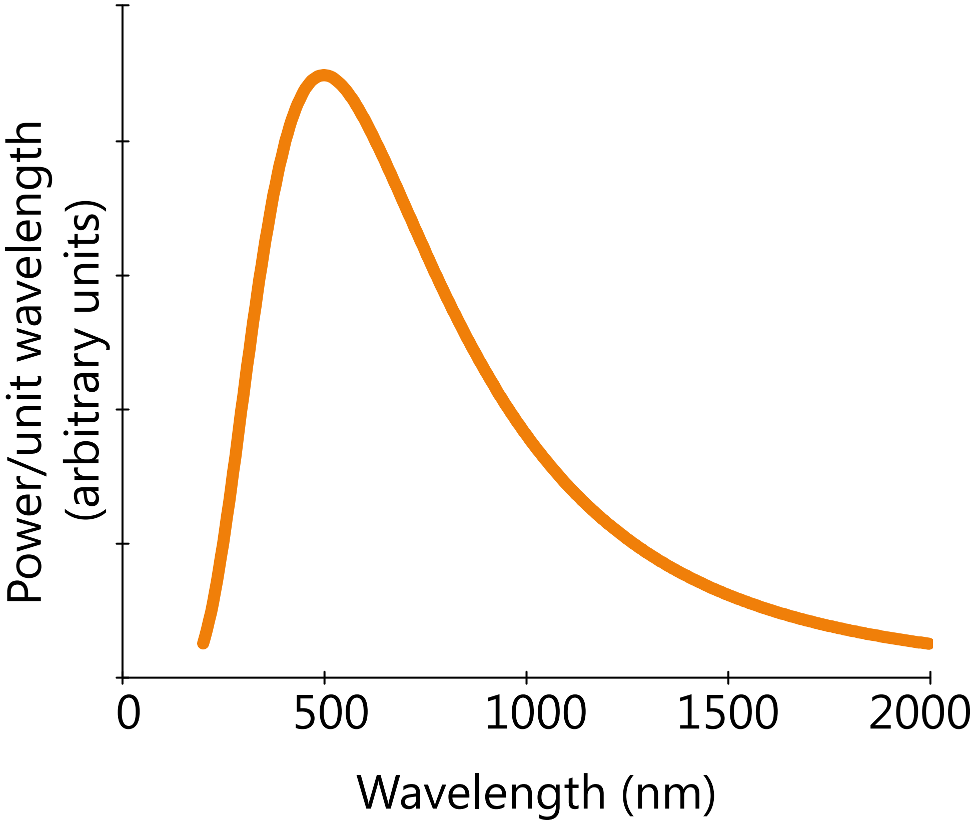
Light

Quantum mechanics for scientists and engineers

David Miller

Black-body spectrum

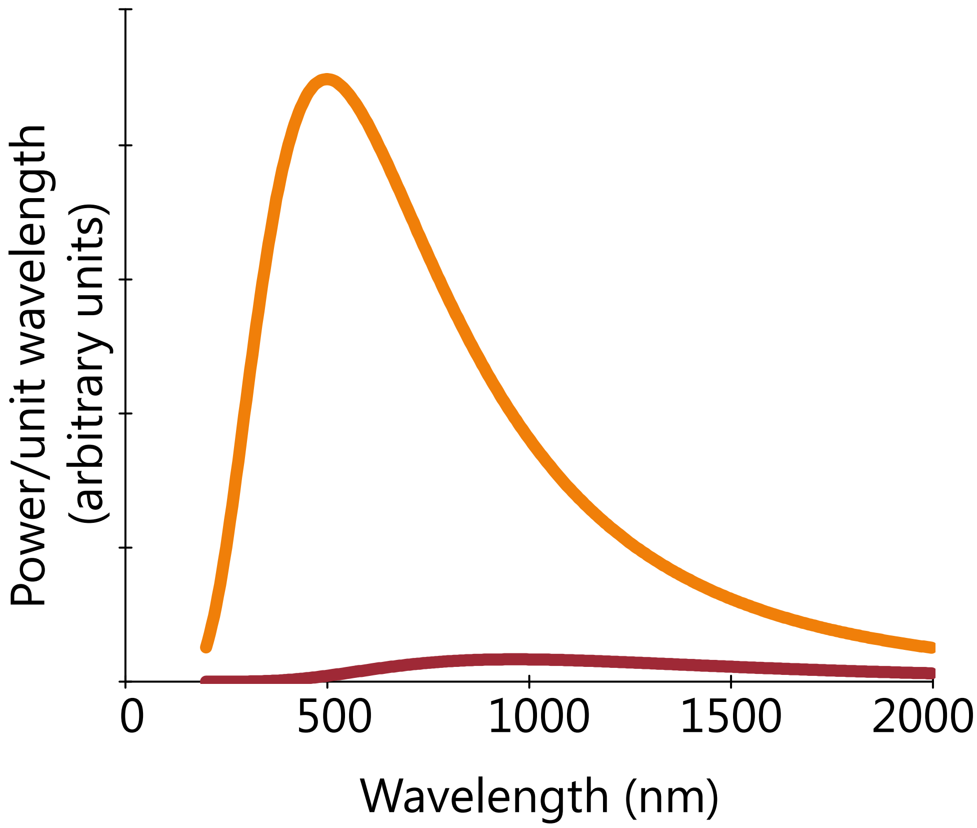
- Output power (per unit wavelength)
  - For a black body at 5800K
    - approximately like the sun



Black-body spectrum

Output power (per unit wavelength)

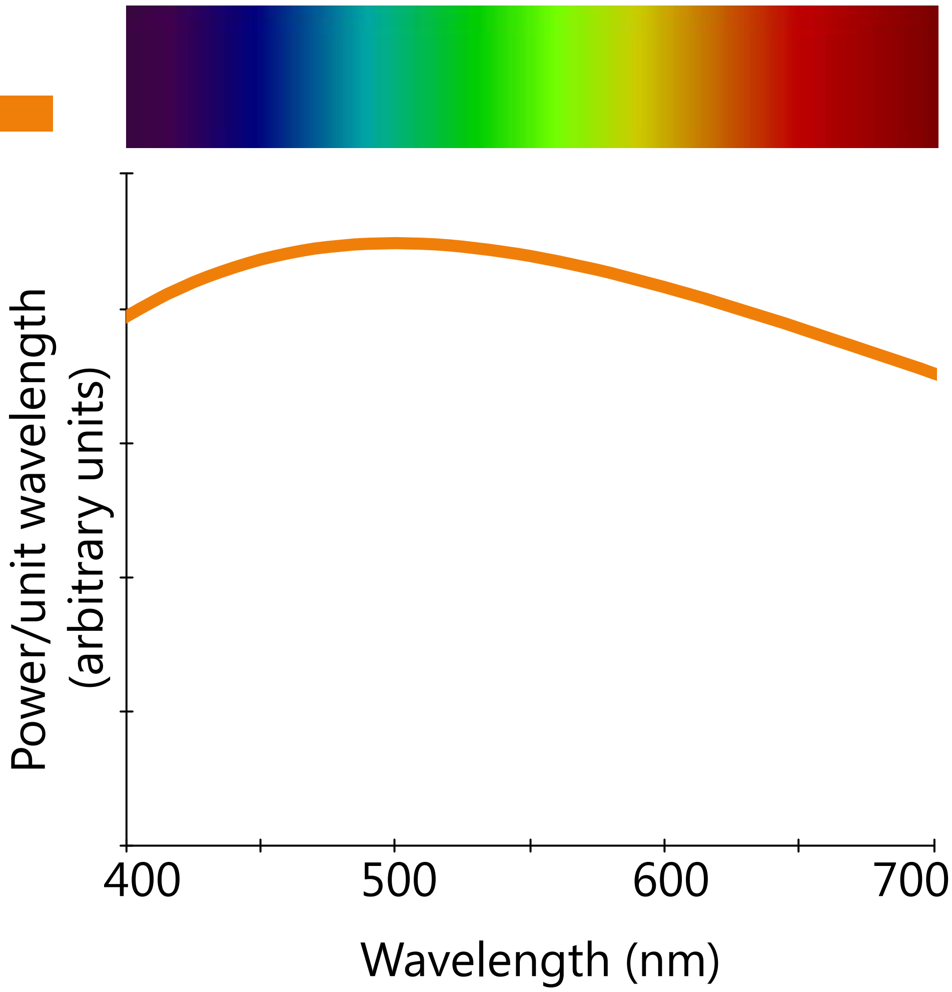
- For a black body at 5800K
  - approximately like the sun
- For a black body at 3000K
  - approximately like an incandescent light bulb



Black-body spectrum

Visible light spectrum

- For a black body at 5800K
  - approximately like the sun



Black-body spectrum

Visible light spectrum

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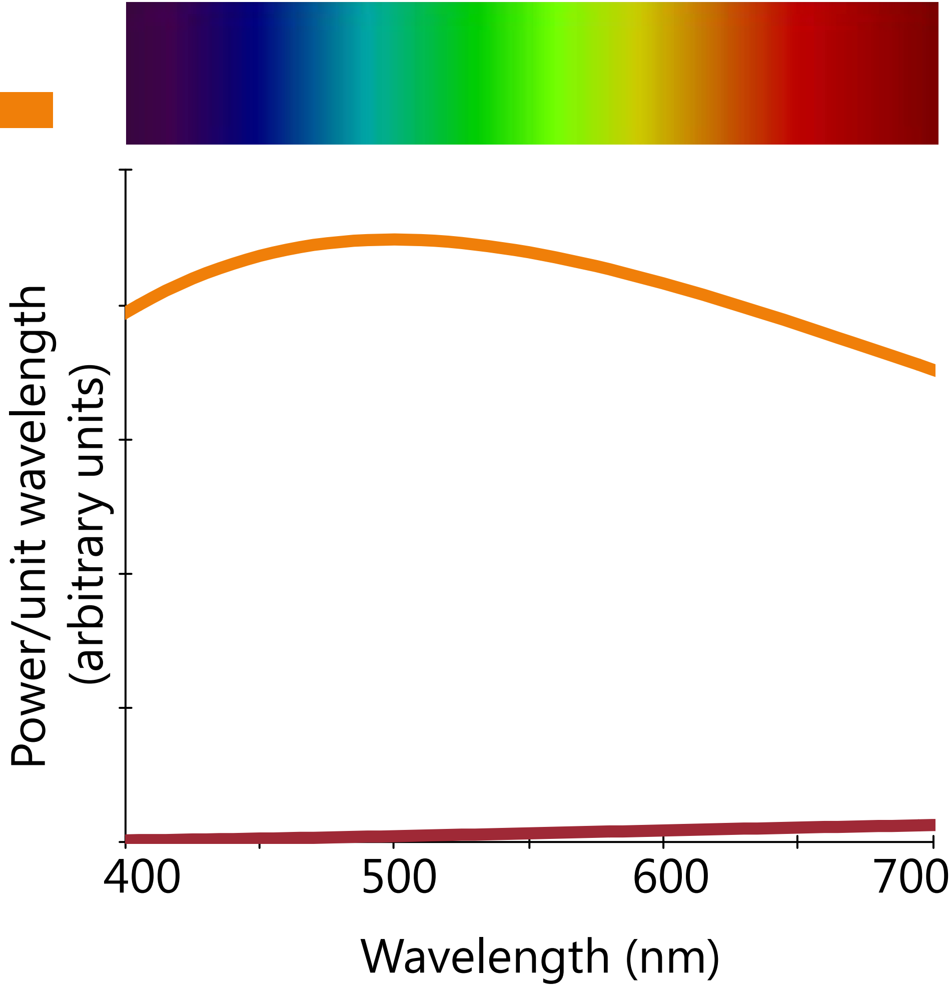

Black-body spectrum

Visible light spectrum

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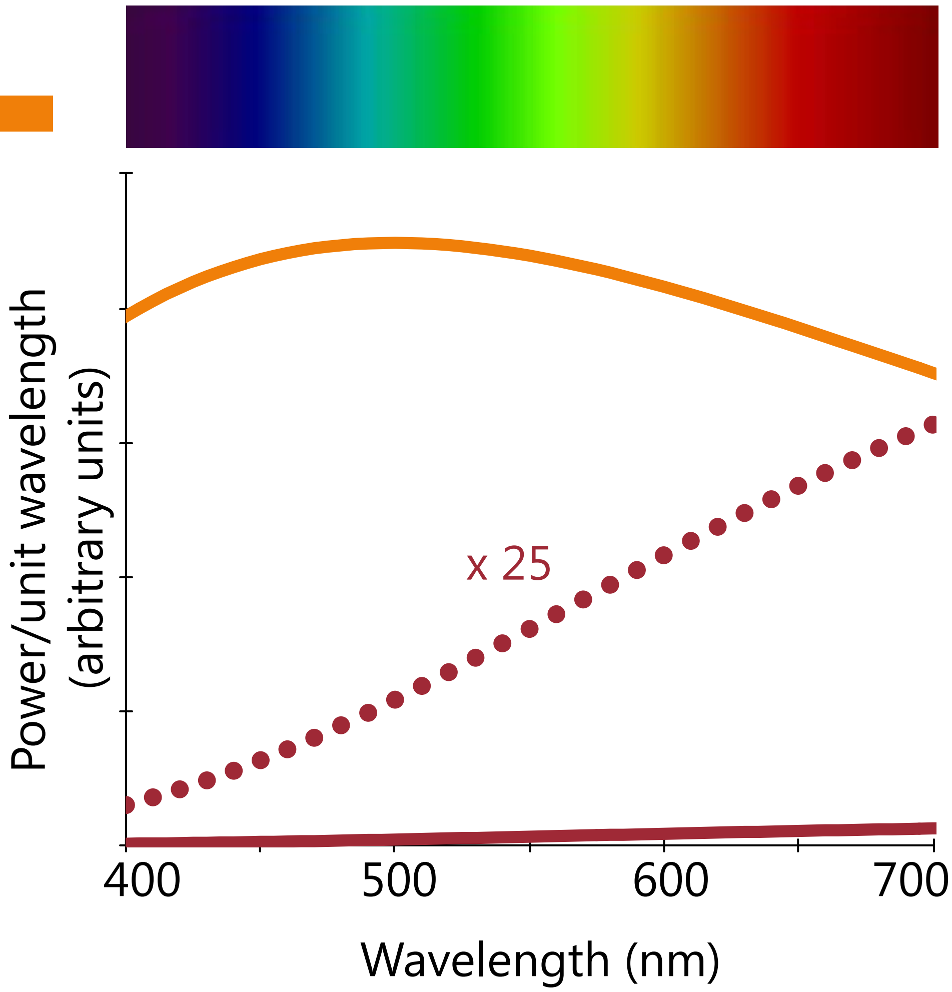

Black-body spectrum

Output power (per unit wavelength)

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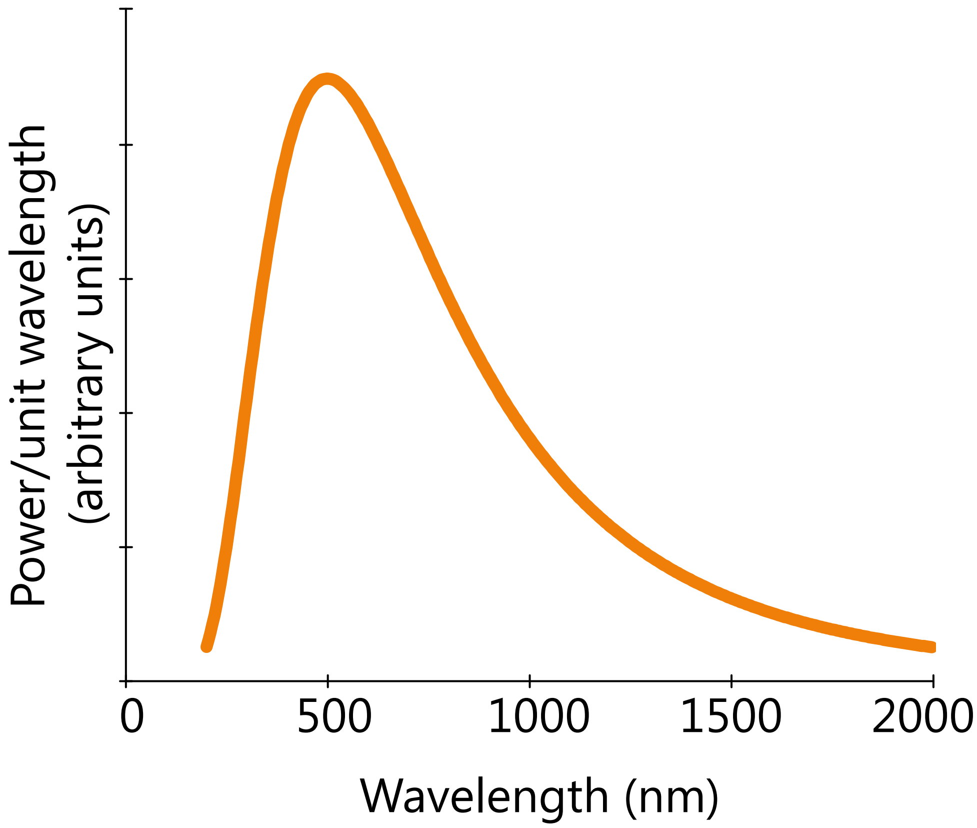
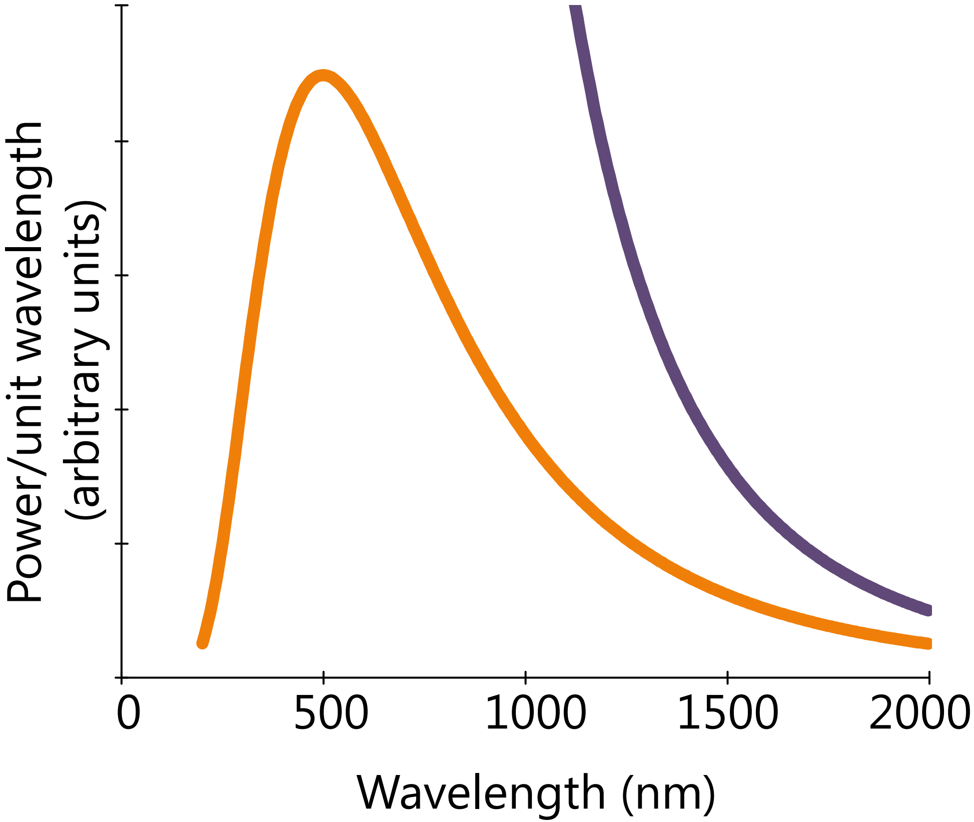
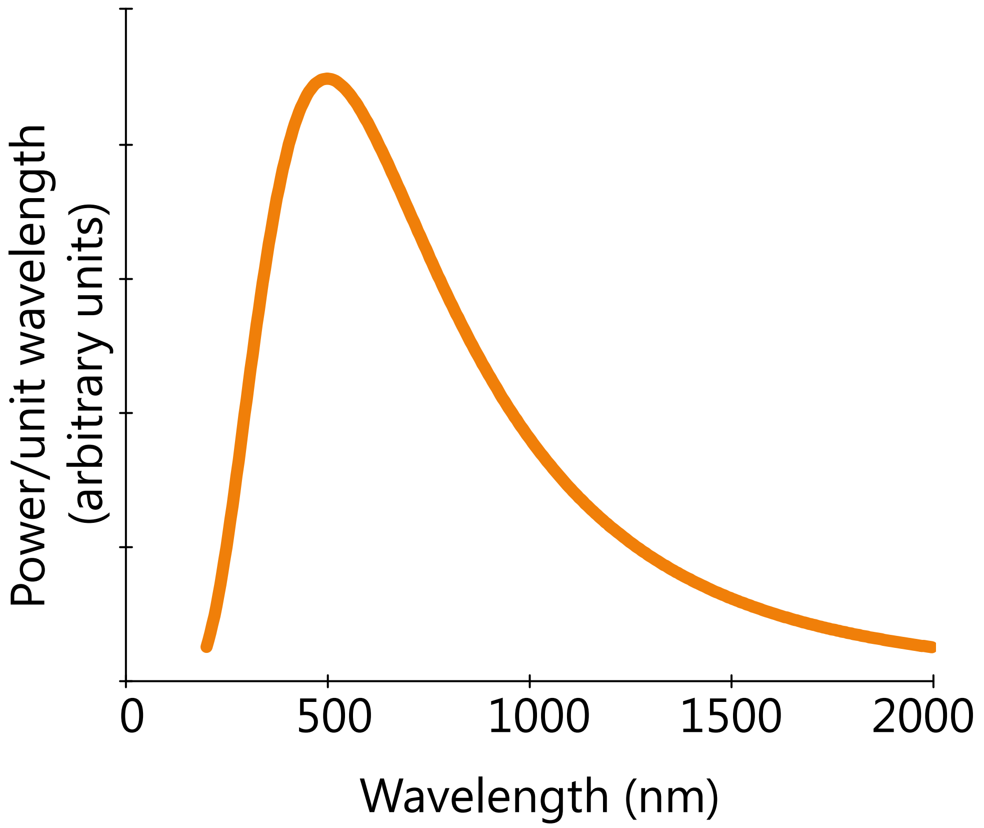


Black-body spectrum

Output power (per unit wavelength)
- For a black body at 5800K
  - approximately like the sun
- The Rayleigh-Jeans classical model gives the
  - “ultra-violet catastrophe”
    - showing no good explanation for the shape of the curve



Black-body spectrum



Planck's proposal

Light is emitted in quanta of energy

$$E = h\nu$$

where ν (Greek letter "nu")

is the light's frequency in Hz (Hertz) and

h is Planck's constant

$$h = 6.62606957 \times 10^{-34}\ J\ s$$

(Joule seconds)

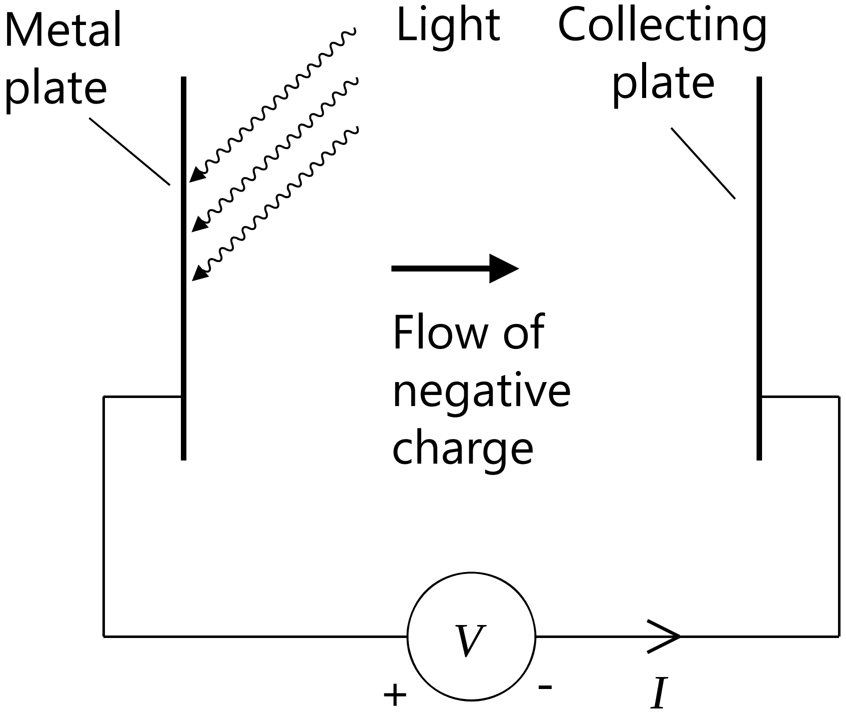
Photoelectric effect

Shining ultraviolet light on the metal plate

- gives flow of negative charge (Hertz, 1887)

Flow can be stopped with a specific voltage

- independent of the brightness
- but dependent only on the frequency (Lenard, 1902)



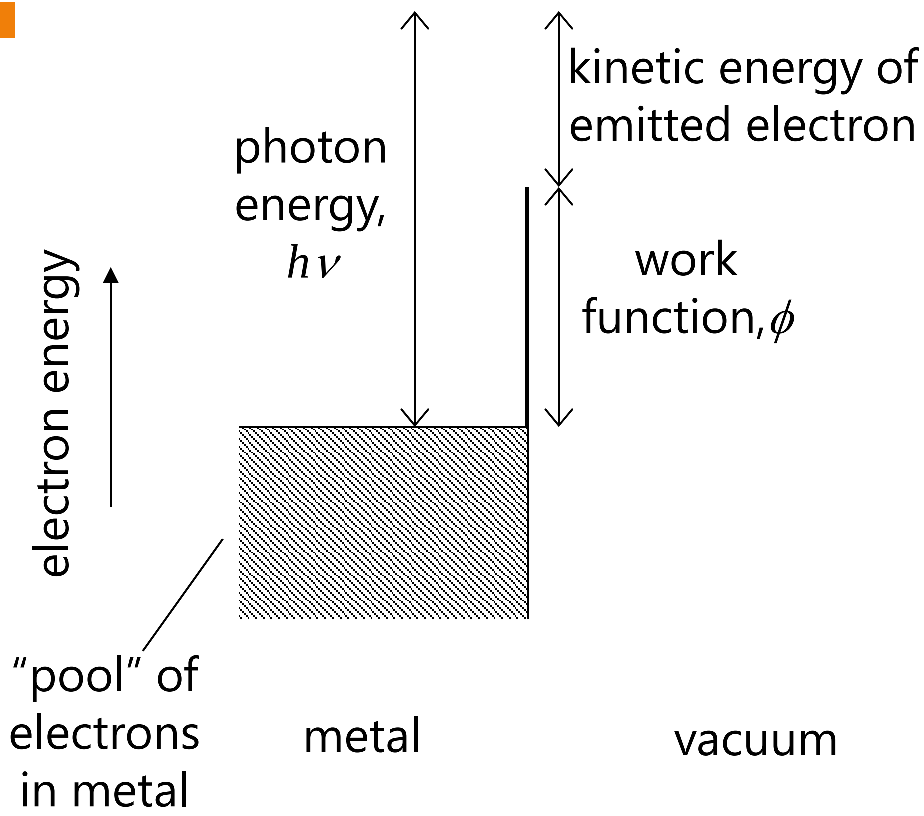
Photoelectric effect

Einstein's proposal (1905)

- light is actually made up out of particles
  - photons, of energy $E = h\nu$

The kinetic energy of the emitted electrons

- is the energy left over after the electron has been "lifted" over the work function barrier



Wave-particle duality

How can light simultaneously be

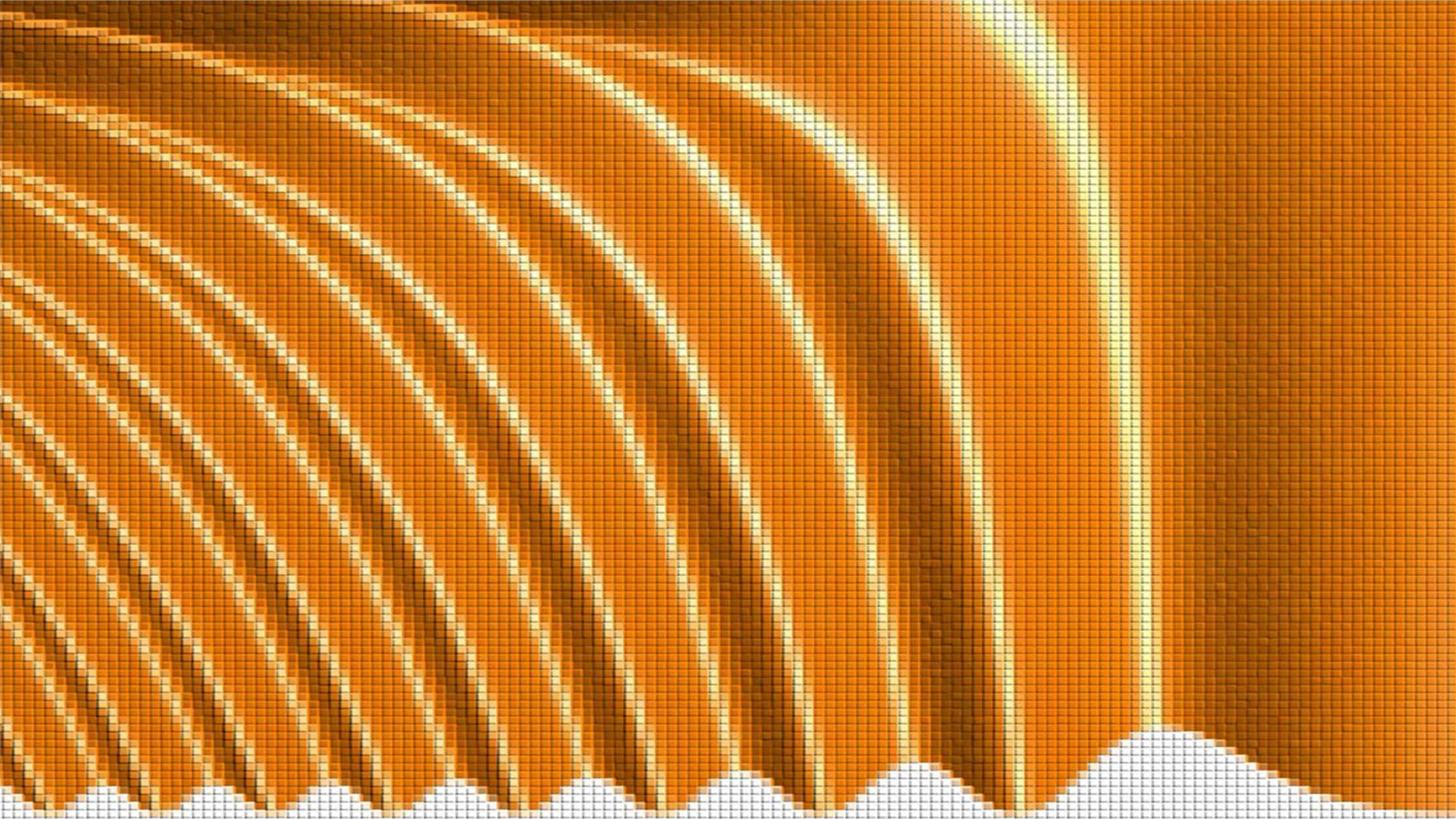
- a wave and a particle?

In the end, this is arguably not a problem for quantum mechanics

- we just need to avoid bringing along all the classical attributes of particles and of waves

The wave-particle duality of light is verified trillions of times a day

- in optical fiber communications

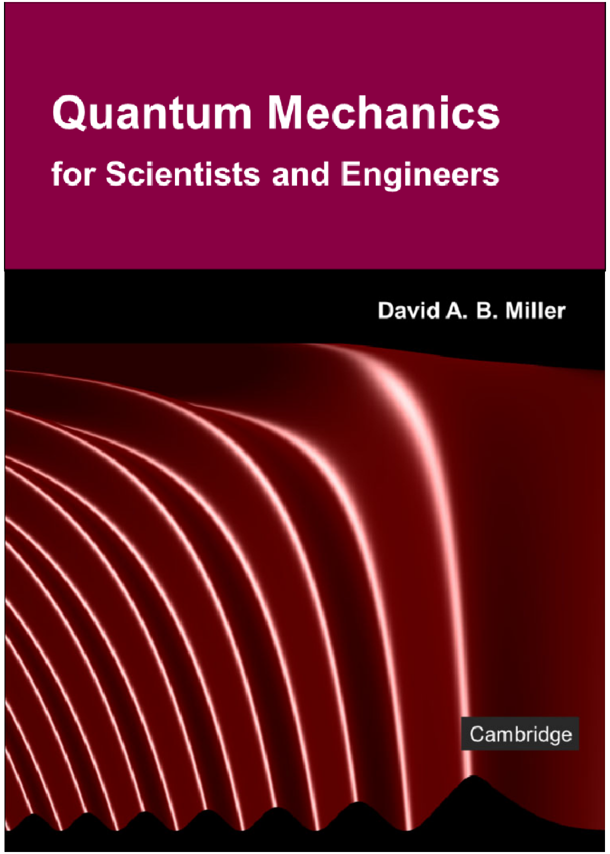


1 Introduction to quantum mechanics

Slides: Lecture 1c Matter

Text reference: Quantum Mechanics for Scientists and Engineers

Section 1.1



Introduction to quantum mechanics

Matter

Quantum mechanics for scientists and engineers

David Miller

Hydrogen atom emission spectra

H-delta 410.2 nm | H-gamma 431.4 nm | H-beta 486.1 nm | H-alpha 656.3 nm

Hot hydrogen emits light

- in a set of spectral lines
  - Balmer series
    - set of lines in the visible spectrum

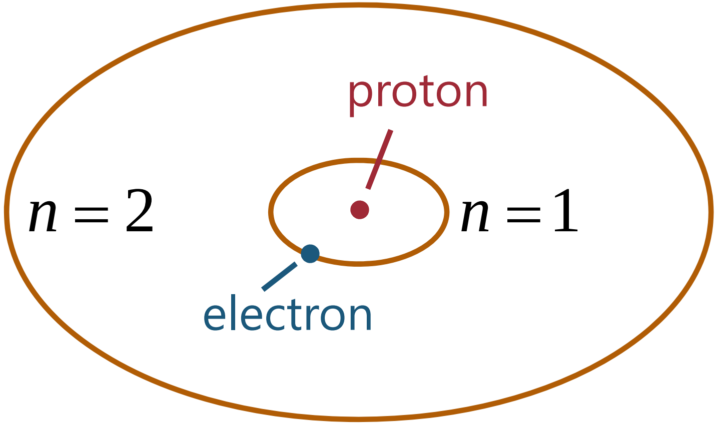
Bohr model of the hydrogen atom

A small negatively charged electron

orbits a small positively charged core (the proton)

like a planet round a sun

but with electrostatic attraction



Key assumption (Neils Bohr, 1913)

angular momentum is "quantized"

in units of Planck's constant, h, over 2π

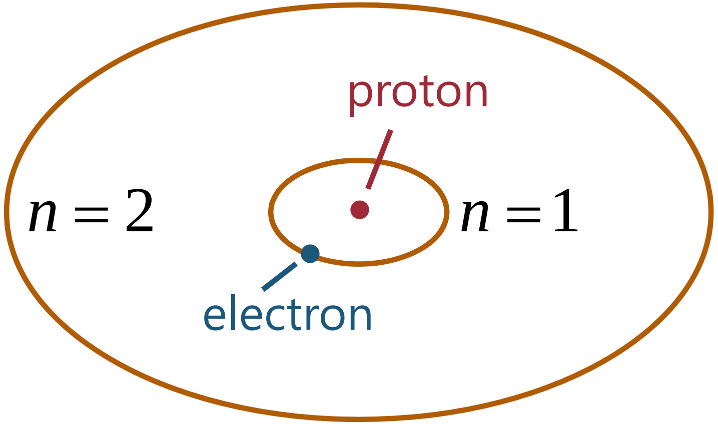
$$\frac{h}{2\pi} \equiv \hbar$$

"h bar"

Bohr model of the hydrogen atom

The model does give the photon energies of the spectral lines

as the separations of the energies of the different orbits



$$\frac{h}{2\pi} \equiv \hbar$$

"h bar"

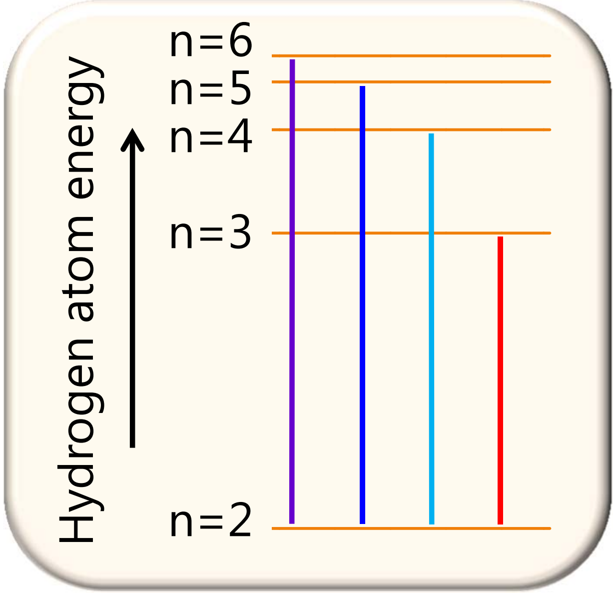
Hydrogen atom emission spectra

H-delta
410.2 nm
n=6 to
n=2

H-gamma
431.4 nm
n=5 to
n=2

H-beta
486.1 nm
n=4 to
n=2

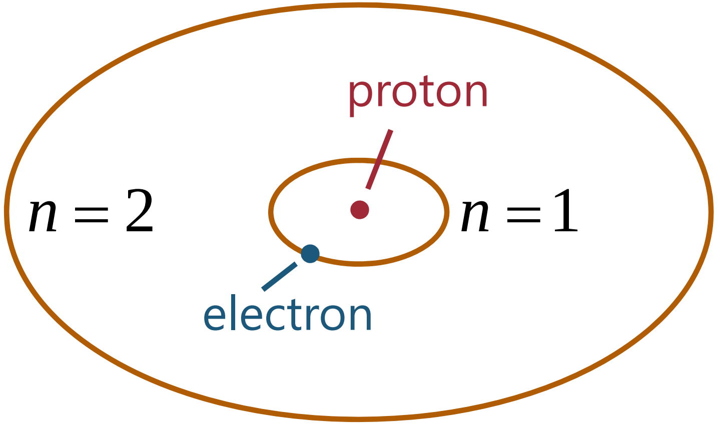
H-alpha
656.3 nm
n=3 to
n=2



Bohr model of the hydrogen atom

The model

- successfully introduces Planck's constant into the theory of matter
  - gets the approximate size of the atom right
    - the characteristic size is the Bohr radius ~ 0.05 nm
      - 0.5 Å (Ångströms)



$$\frac{h}{2\pi} \equiv \hbar$$

"h bar"

Bohr model of the hydrogen atom

The model does not get the angular momentum quite right

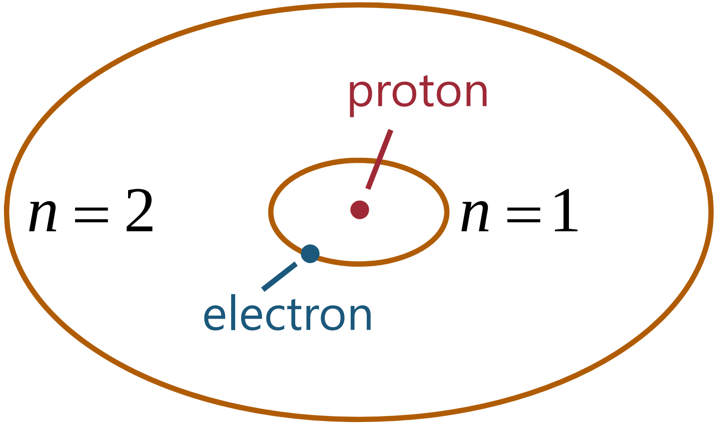
- though the quantization in $\hbar$ units remains very important

It appears to predict the atom would radiate all the time

- from the orbiting electron

The atom does not "look" like this

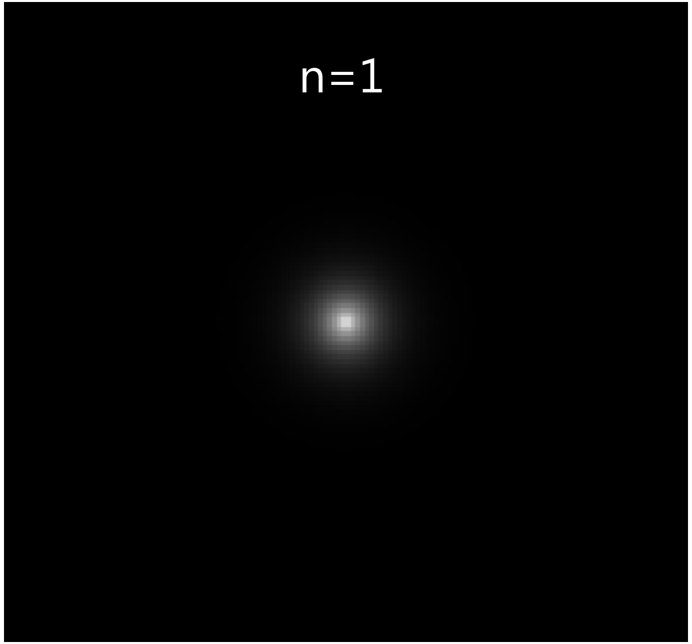
- it is not a small "point" electron in a classical orbit

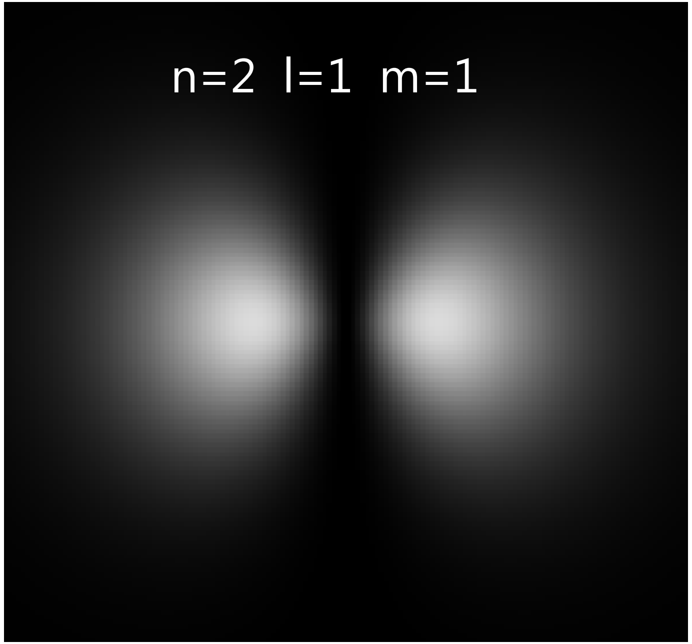


$$\frac{h}{2\pi} \equiv \hbar$$

"h bar"

Hydrogen atom orbitals





Electron charge density in hydrogen orbitals

The electron is not a moving point particle

de Broglie hypothesis

A particle with mass

also behaves as a wave

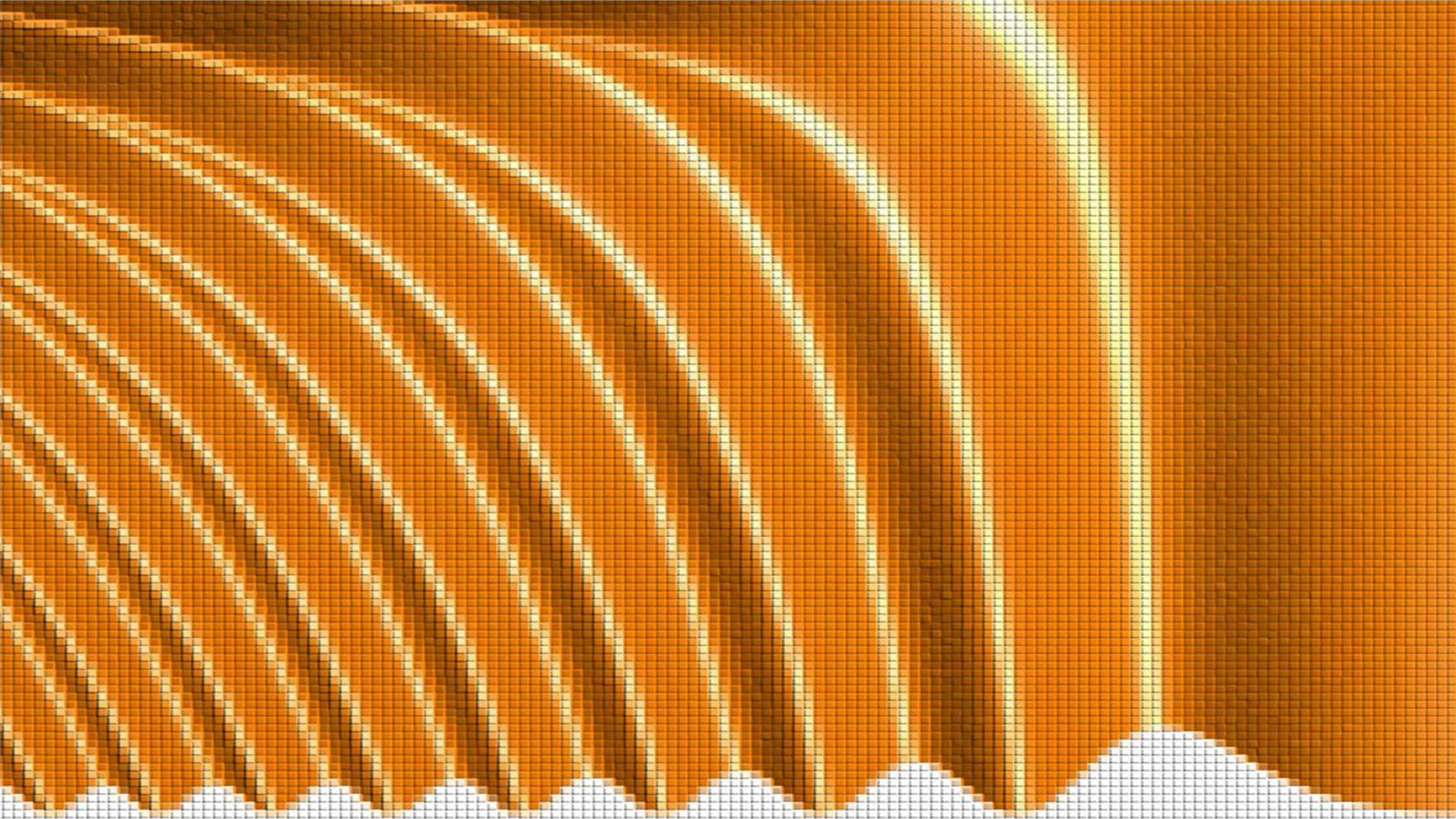
with wavelength

$$\lambda = \frac{h}{p}$$

where p is the particle's momentum

Matrices and waves

- Werner Heisenberg (1925)
  - matrix formulation of quantum mechanics
- Erwin Schrödinger (1926)
  - wave equation
- More key contributions by
  - Max Born, Pascual Jordan, Paul Dirac, John von Neumann, …

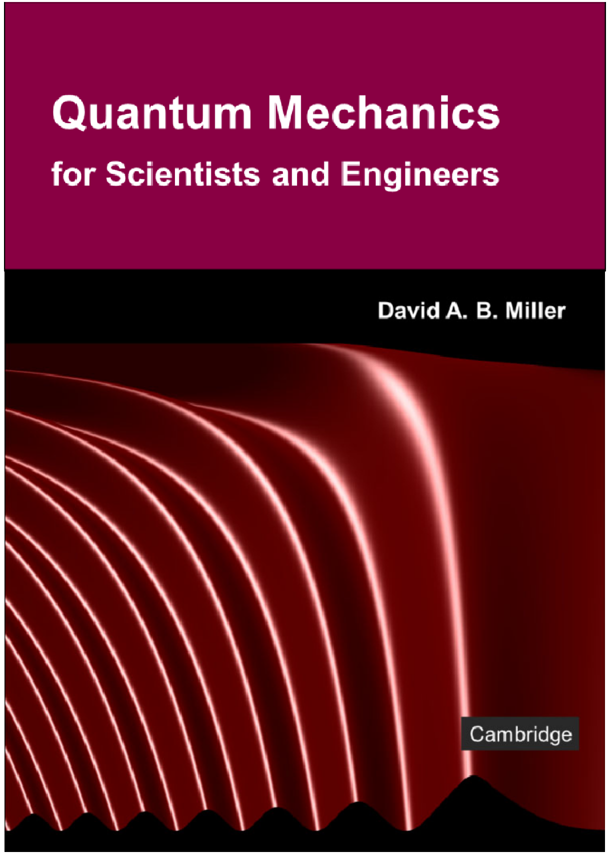


1 Introduction to quantum mechanics

Slides: Lecture 1d The usefulness of quantum mechanics

Text reference: Quantum Mechanics for Scientists and Engineers

Section 1.1



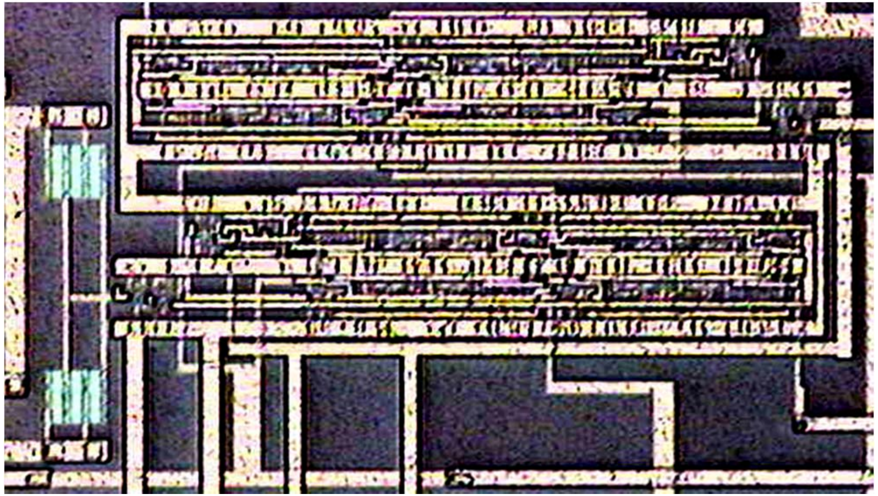
Introduction to quantum mechanics

Usefulness of quantum mechanics

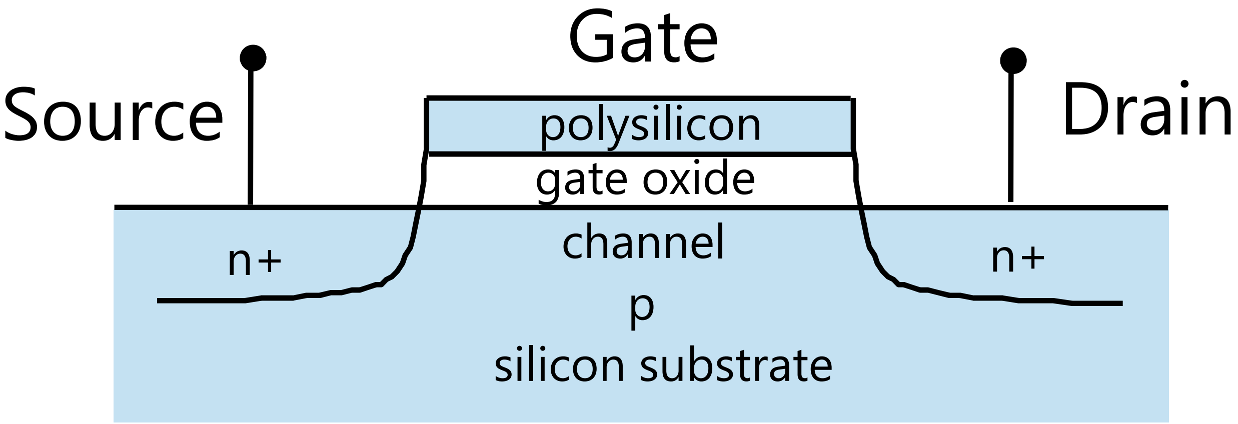
Quantum mechanics for scientists and engineers

David Miller

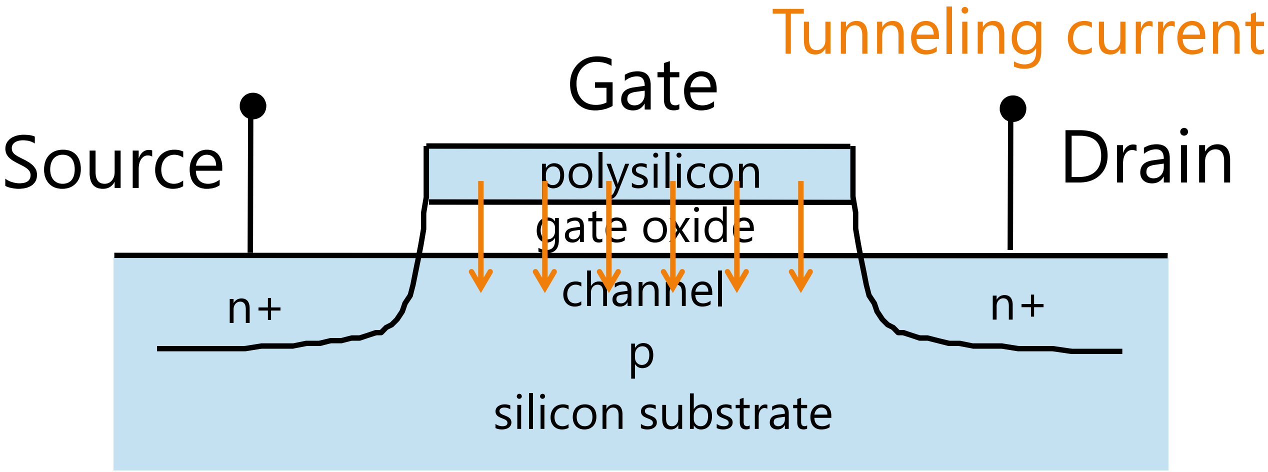
Transistors and integrated circuits



Transistors and gate tunneling



Transistors and gate tunneling

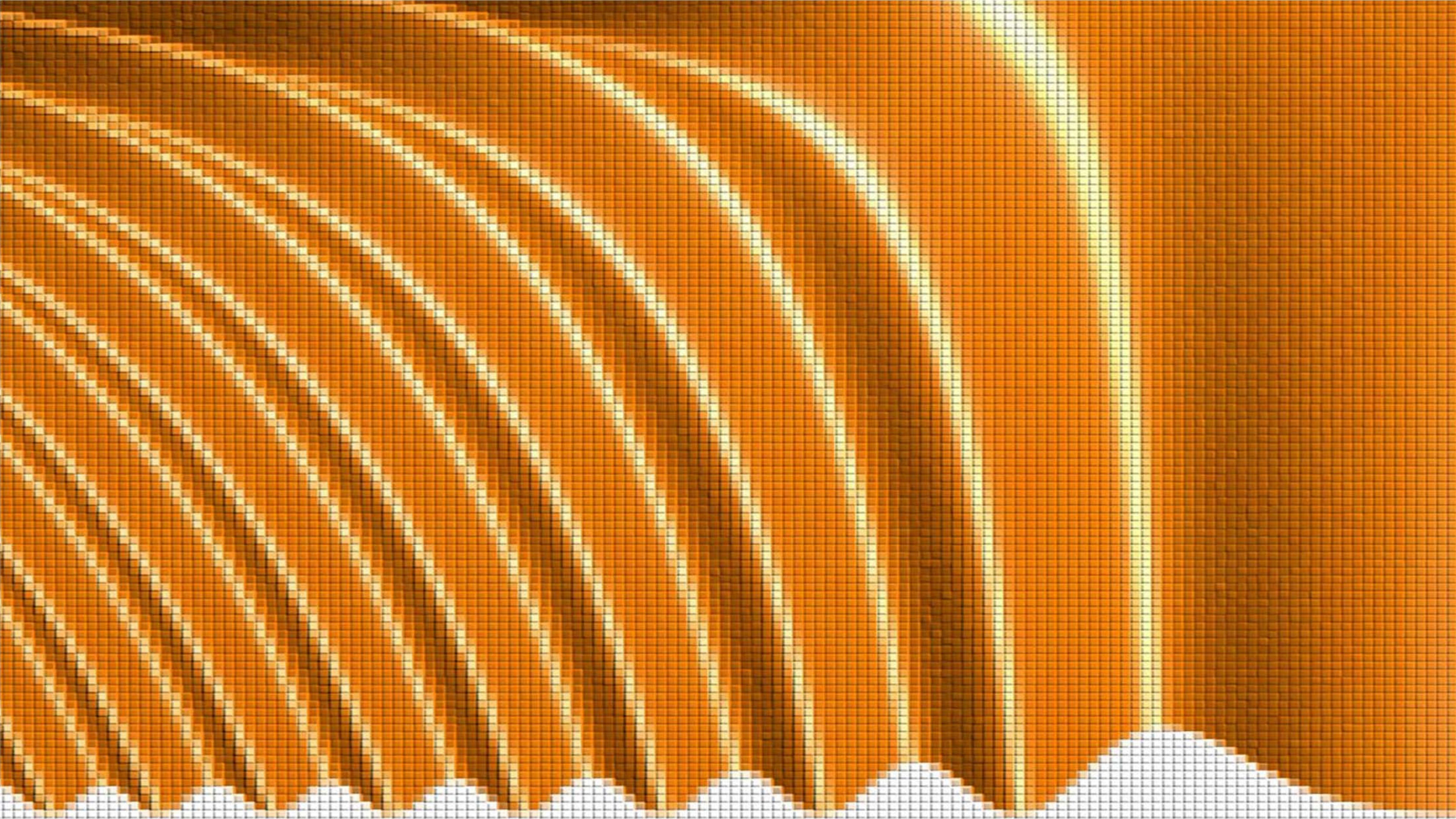


With smaller transistors

the gate oxide becomes thinner

allowing quantum mechanical tunneling

giving undesired gate leakage current

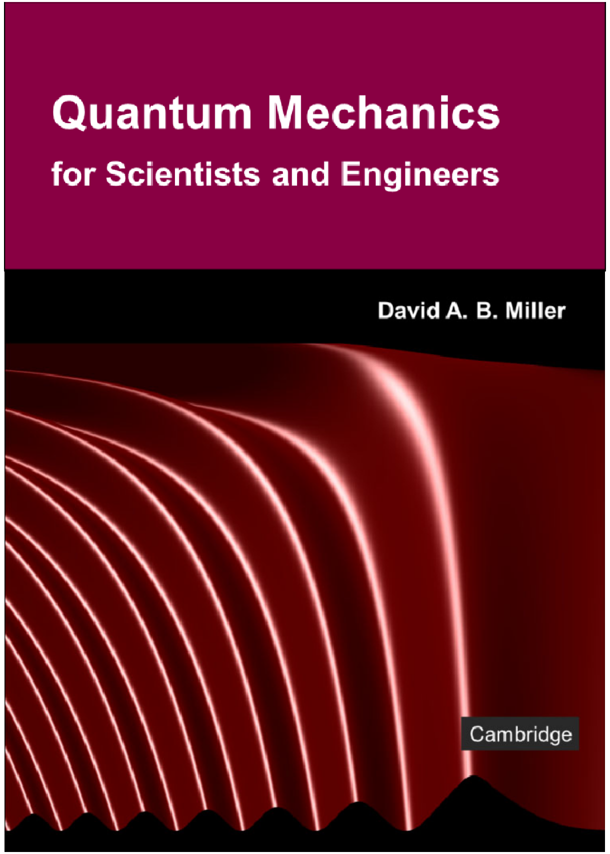


1 Introduction to quantum mechanics

Slides: Lecture 1e Science, philosophy and meaning

Text reference: Quantum Mechanics for Scientists and Engineers

Sections 1.2 – 1.3



Introduction to quantum mechanics

Science, philosophy and meaning

Quantum mechanics for scientists and engineers

David Miller

Reconstructing science

What did you want to measure?

Schrödinger’s cat

More bizarre concepts

Quantum mechanics works

Using quantum mechanics