EINFÜHRUNG IN DIE QUANTENMECHANIK

PROF. DR. R. FRIEDRICH

VORLESUNG SS 2012

WWU MÜNSTER

VORLESUNGEN IM RAHMEN DES MODULS ATOM- UND QUANTENPHYSIK

EINFÜHRUNG IN DIE QUANTENMECHANIK (4ECTS, R.F.)

ÜBUNGEN(4ECTS,R.F.,S.GUREVICH,M.WILCZEK)

ATOM-UND MOLEKÜLPHYSIK (2ECTS, PROF. HANNE)

SPRECHSTUNDE

- **MITTWOCH, 10-11 UHR**
- **WILHELM-KLEMM-STR. 9, Zi 315**

ÜBUNGEN

- MÜNDLICH/SCHRIFTLICH
- **ZULASSUNG ZUR KLAUSUR: 50,50 %**
- ÜBUNGSGRUPPENEINTEILUNG S. INTERNET
- **KLAUSUR-TERMIN 16.7., 14.00-17.00 (18.00)**
- NACHKLAUSUR 24.9. 14.00-17.00 (18.00)

'THEORIE-VORLESUNGEN'

- **EINFÜHRUNG IN DIE QUANTENMECHANIK**
- **QUANTENPHYSIK (WS 2012/13)**
- **STATISTISCHE PHYSIK (SS 2013)**

AG SELBSTORGANISATION UND KOMPLEXITÄT

SELBSTORGANISATION IN SYSTEMEN FERN VOM GLEICHGEWICHT

ANALYSE KOMPLEXER SYSTEME

TURBULENTE FELDER

Einführende Literatur:

H. Haken, H.C. Wolf, The Physics of Atoms and Quanta (Springer Verlag)

R. P. Feynman, R. B. Leighton, M. Sands; Feynman Vorlesungen über Physik Band III: Quantenmechanik (Oldenburg 2007)

Th. Fliessbach; Quantenmechanik, Lehrbuch zur Theoretischen Physik Band III (Spektrum Akademischer Verlag 2008)

G. Münster, Quantentheorie (De Gruyter, 2010)

Literatur für Fortgeschrittene:

L. D. Landau, E. M. Lifshitz, Lehrbuch der Theoretischen Physik Band 3: Quantenmechanik

E. Fick; Einführung in die Grundlagen der Quantentheorie (1988)

C. Cohen-Tannoudji, B. Diu, F. Laloe, F. Streubel; Quantenmechanik Teil I, II (Gruyter 2009)

VORLESUNGSPLAN SS 2012

- **MATERIE-WELLEN**
- **SCHRÖDINGER-GLEICHUNG**
- **WELLENMECHANIK IN 1 DIMENSION**
- **KONZEPTE DER QUANTENMECHANIK**
- **HARMONISCHER OSZILLATOR**
- **WASSERSTOFF-ATOM**

PARTICLE-WAVE DUALITY

- LIGHT: WAVE PROPERTIES

- ELECTRONS, ATOMS: PARTICLE PROPERTIES

- PARTICLE-WAVE DUALITY
- MAX-PLANCK, A. EINSTEIN: PHOTONS
- LOUIS DE BROGLIE: MATTER WAVES

PARTICLES VERSUS WAVES

- ENERGY
- MOMENTUM
- MASS

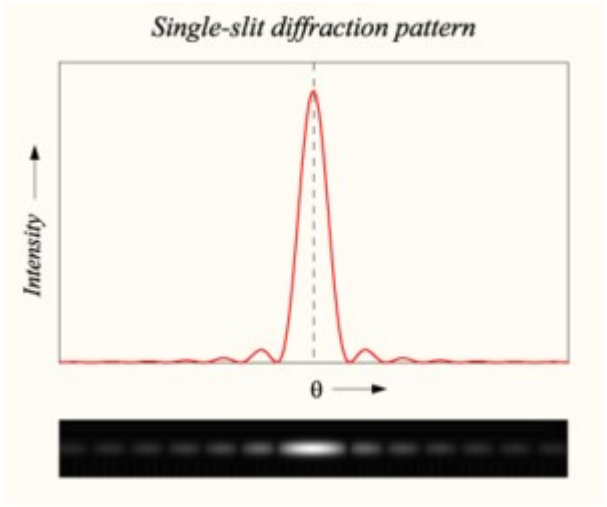
- COLLISIONS
- GAS OF PARTICLES

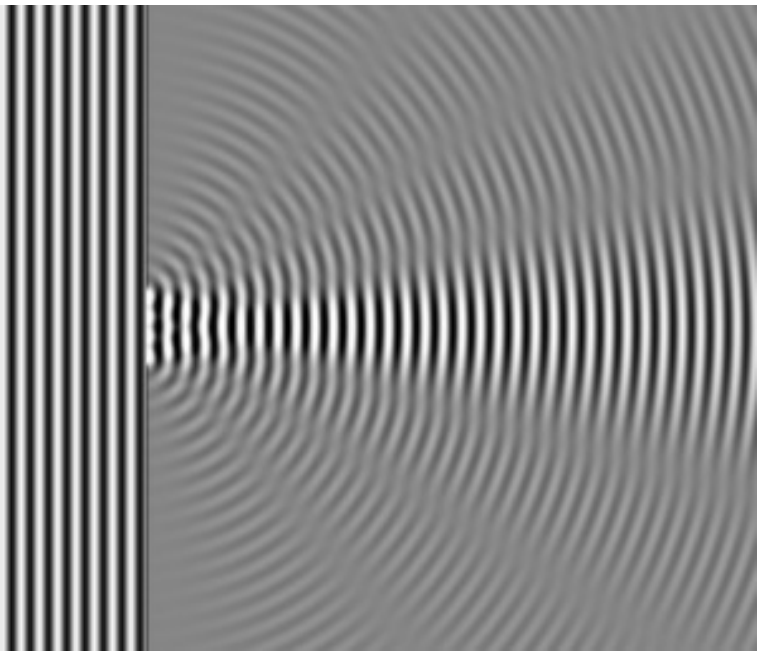
- FREQUENCY
- WAVE LENGTH
- DIFFRACTION

- DIFFRACTION, INTERFERENCE

EXPERIMENTS
WAVE CHARACTER

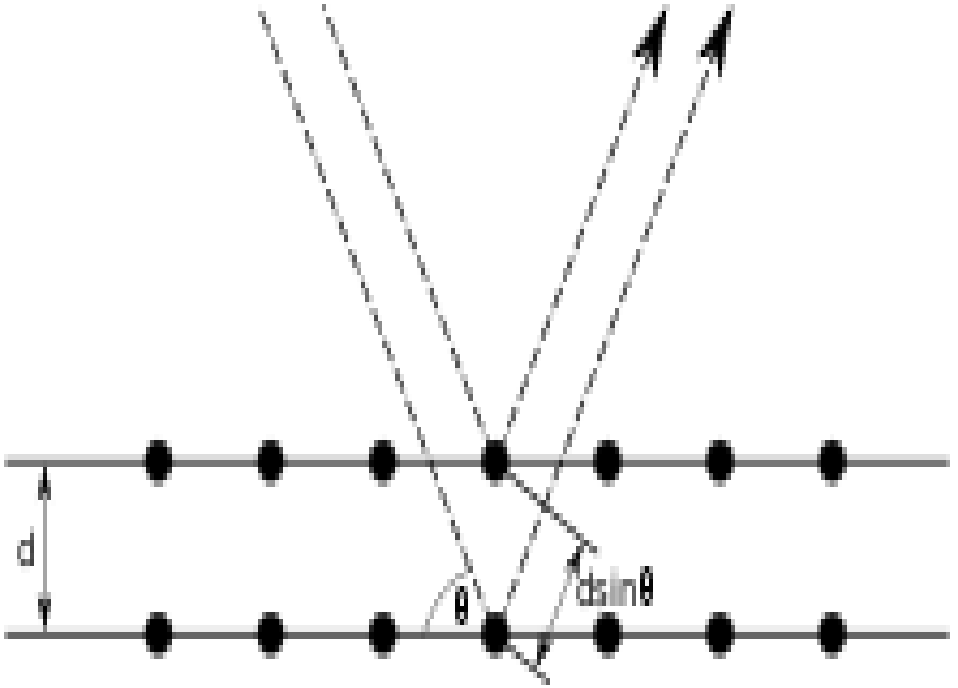
- DIFFRACTION GRATINGS,
- BRAGG REFLECTION, CRYSTALS
- INTERFERENCE
- DOUBLE SLIT EXPERIMENT





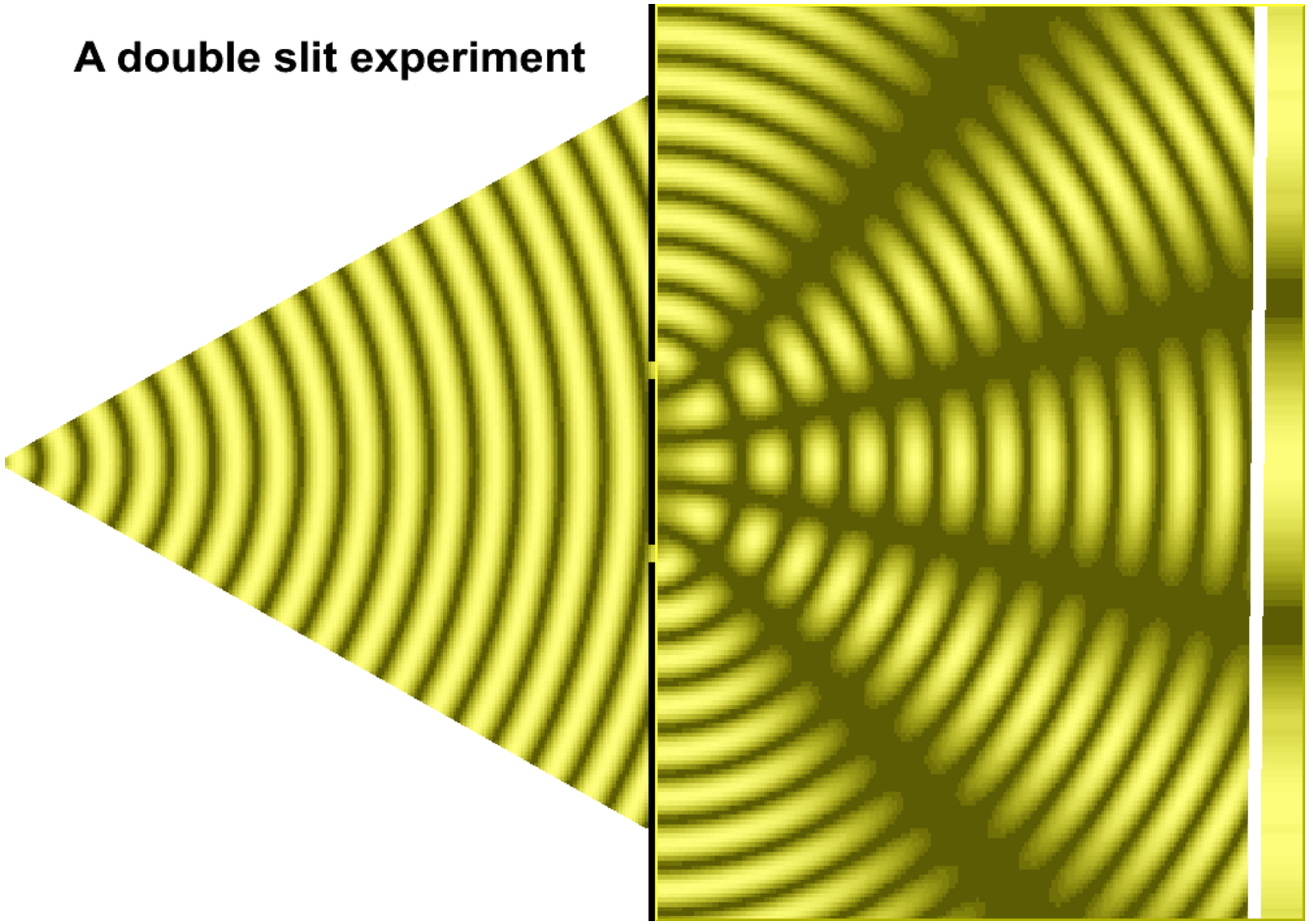
BRAGG-DIFFRACTION

- X-RAY DIFFRACTION
- CONSTRUCTIVE INTERFERENCE
- BRAGG CONDITION



$$2\,D\sin\Theta = \Lambda$$

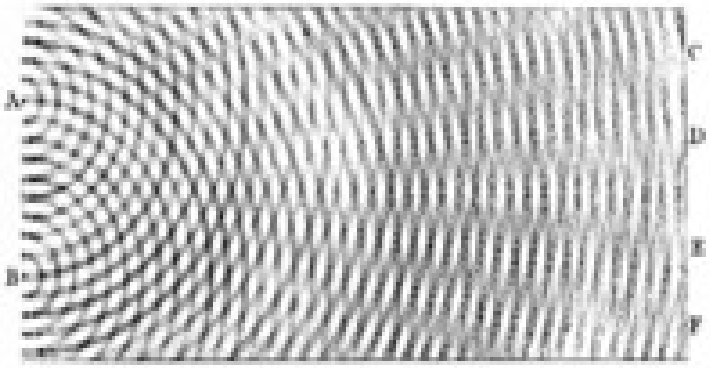
DOUBLE SLIT EXPERIMENT



- R. FEYNMAN

YOUNG'S DOUBLE SLIT EXPERIMENT WITH LIGHT

- THOMAS YOUNG (1803) EXPERIMENTS AND CALCULATIONS RELATIVE TO PHYSICAL OPTICS
- EXPLANATION: HUYGENS-FRESNEL PRINCIPLES OF OPTICS
- WAVE-CHARACTER OF LIGHT

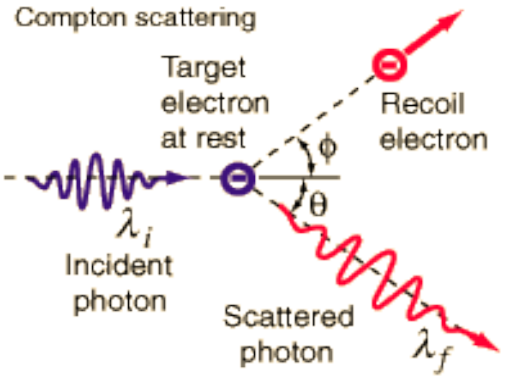


EXPERIMENTS
PARTICLE PROPERTIES

- INTERACTIONS
- COLLISION
- GASES: ENSEMBLES OF PARTICLES

PARTICLE BEHAVIOUR OF LIGHT

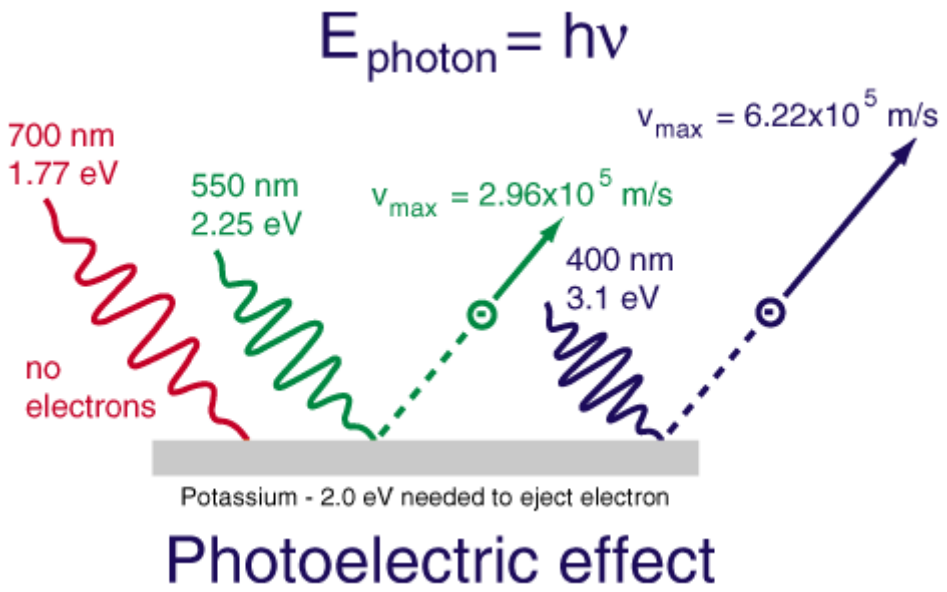
- M. PLANCK (1900): BLACK-BODY RADIATION
- A. EINSTEIN (1905): EXPLANATION OF THE PHOTOELECTRIC EFFECT
- COMPTON EFFECT (NOBEL PRICE 1927)



$$\lambda_i - \lambda_f = \frac{h}{mc}(1 - cos\Theta)$$

PARTICLE BEHAVIOUR OF LIGHT

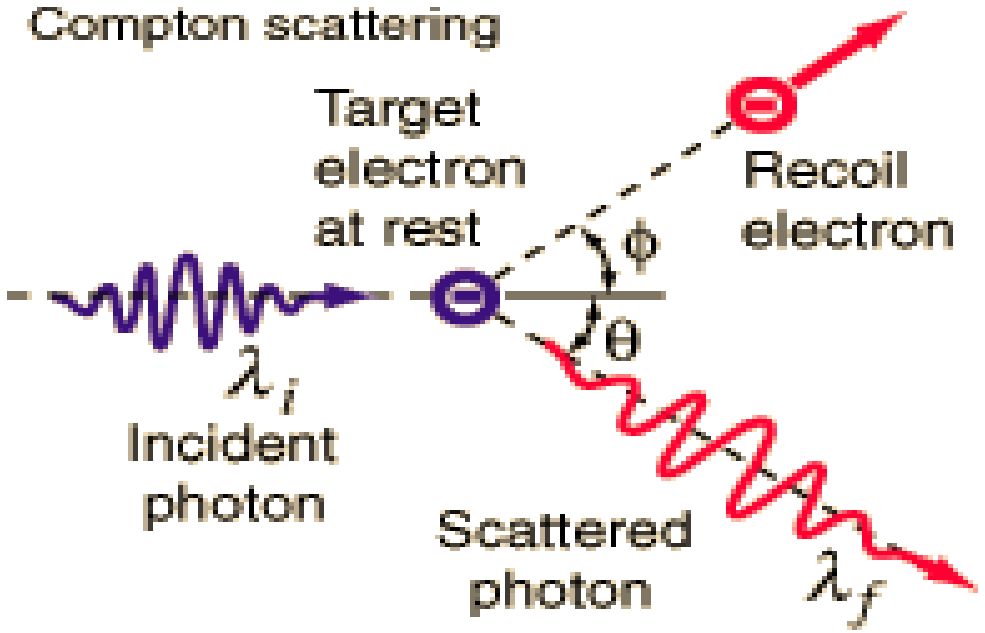
- A. EINSTEIN (1905): EXPLANATION OF THE PHOTOELECTRIC EFFECT



$$m\frac{v^2}{2} = h\nu - eV_A$$

PARTICLE BEHAVIOUR OF LIGHT

- COMPTON EFFECT (NOBEL PRICE 1927)



$$\lambda_i - \lambda_f = \frac{h}{mc}(1 - cos\Theta)$$

WAVE-PARTICLE DUALITY
LIGHT WAVES, PHOTONS

- ENERGY
- MOMENTUM
- MASS: M=0

- FREQUENCY
- WAVE LENGTH
- WAVE VECTOR

$$E = h\nu = \hbar\omega$$

$$\mathbf{p} = \hbar\mathbf{k}$$

WAVE-PARTICLE DUALITY
LIGHT WAVES, PHOTONS

- ENERGY
- MOMENTUM
- MASS: M=0

- FREQUENCY
- WAVE LENGTH
- WAVE VECTOR

$$E = h\nu = \hbar\omega$$

$$\mathbf{p} = \hbar\mathbf{k}$$

PARTICLE-WAVE DUALITY
MATTER WAVES
(DE BROGLIE 1924)

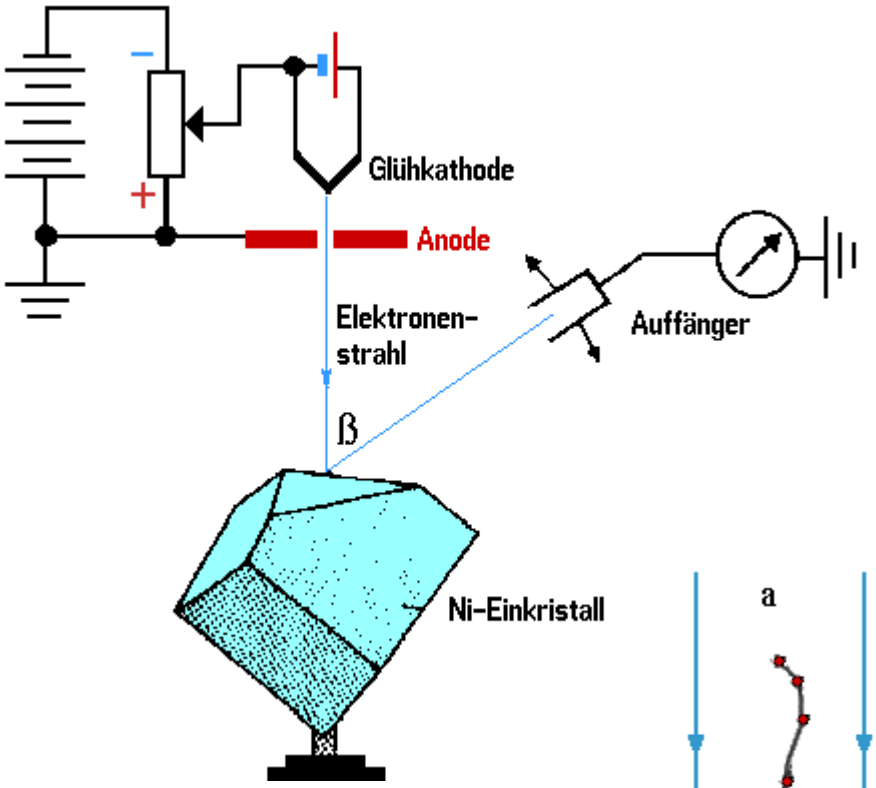
- ENERGY
- MOMENTUM
- MASS: M=0

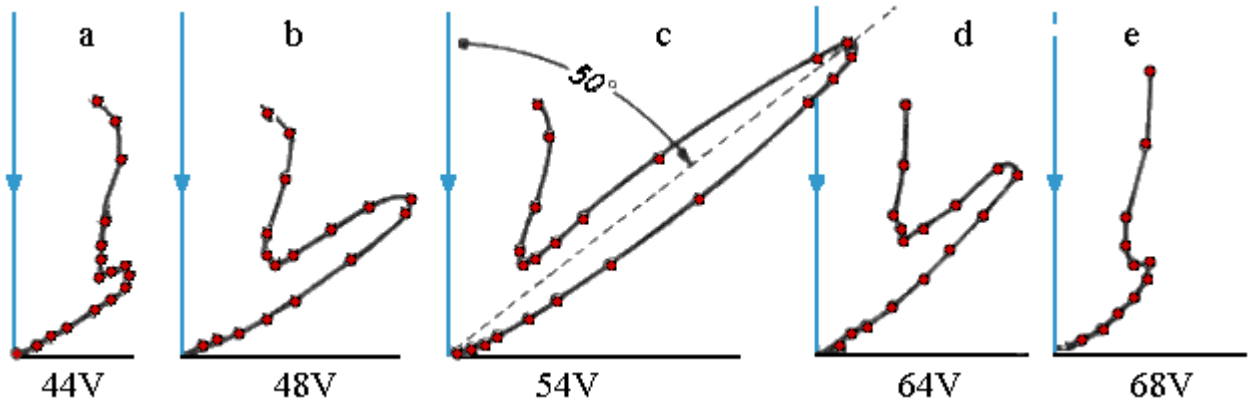
- FREQUENCY
- WAVE LENGTH
- WAVE VECTOR

$$E = h\nu = \hbar\omega$$

$$\mathbf{p} = \hbar\mathbf{k}$$

DAVISSON AND GERMER (1927) FIRST PROOF OF DE BROGLIES HYPOTHESIS





DAVISSON GERMER (1927)

- ACCELERATION BY ELECTRIC FIELD

$$E = \frac{P^2}{2\mathrm{m}} = 54\,eV$$

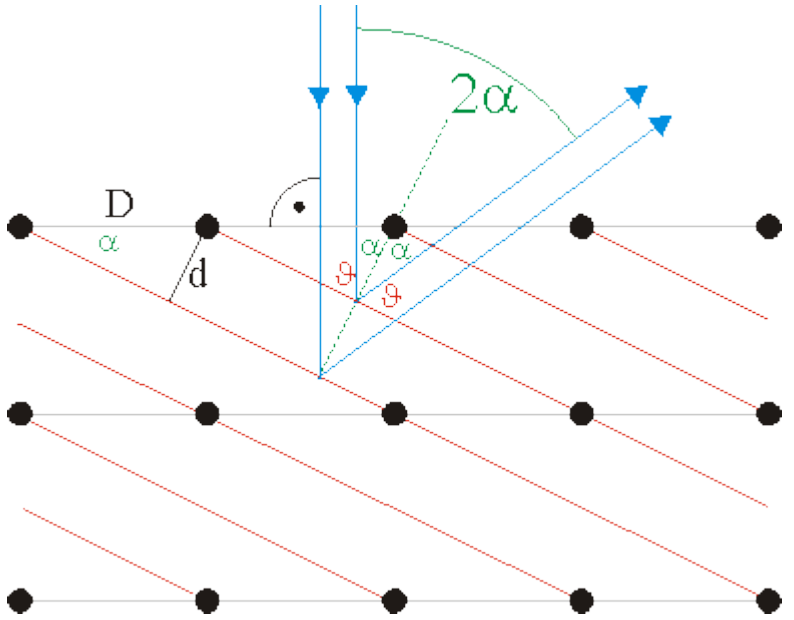
$$p = \sqrt{2\mathrm{m}\,E} = 3{,}97 * 10^{-24}\,Ns$$

$$\lambda = \frac{h}{p} = \frac{6{,}63 * 10^{-34}}{3.97 * 10^{-24}}\,m = 1{,}67 * 10^{-10}\,m$$

- ANGLE (Bragg-Condition)

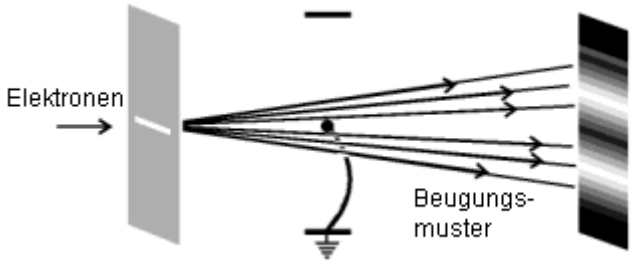
$$\lambda = 2d \sin\theta = 2\mathrm{d} \sin(90 - \alpha)$$

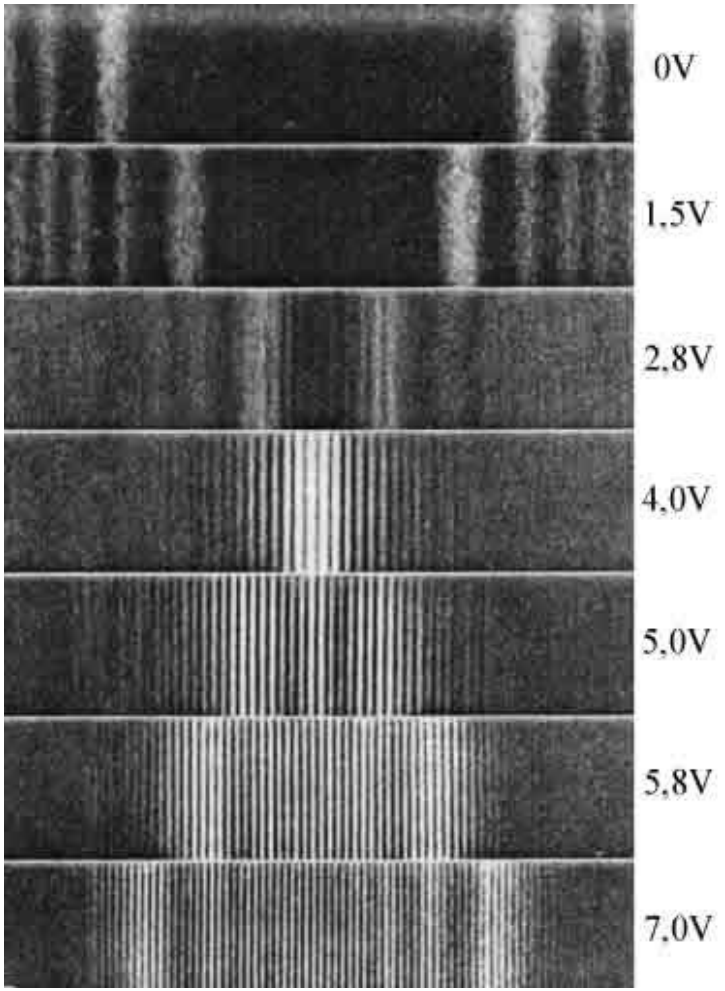
$$\alpha = 50/2 \rightarrow \lambda = 1{,}65 * 10^{-10}\,m$$



DOUBLE SLIT EXPERIMENT WITH PARTICLES

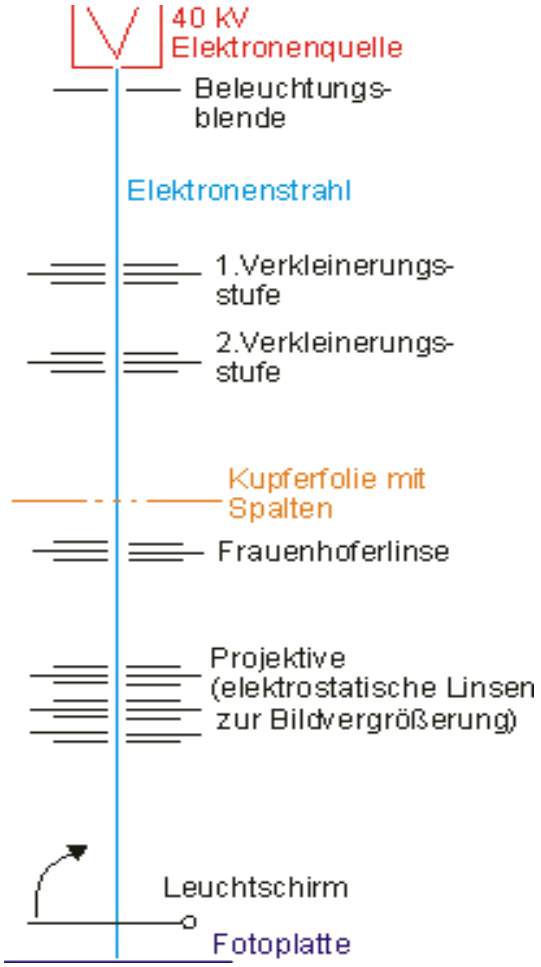
MÖLLENSTEDT, DÜKER EXPERIMENT (1955)





- INTERFERENCE, ELECTRON BEAMS

DOUBLE-SLIT EXPERIMENT
C. JÖNSSON (1957)



- C. Jönsson, Zeitschrift für Physik, 161, 454-474 (1961)

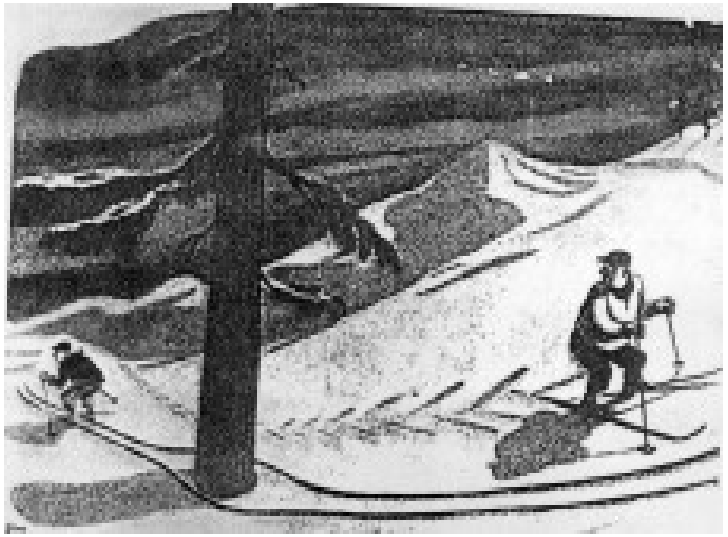
TOP TEN PHYSICAL EXPERIMENTS

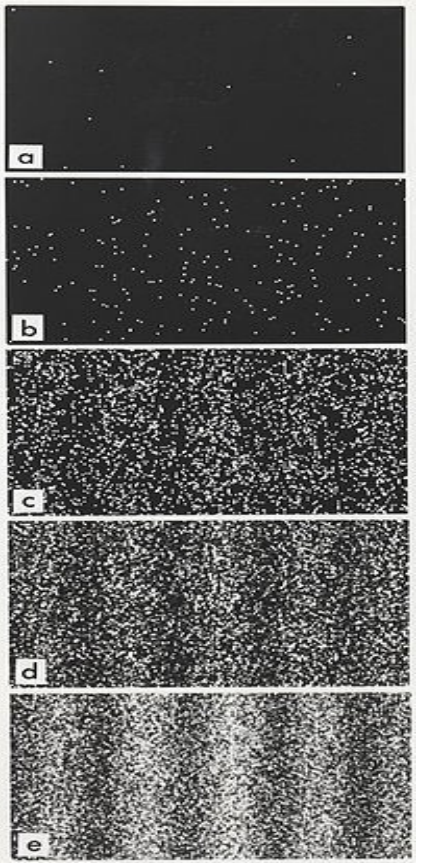
- JÖNSSON DOUBLE SLIT (1961)
- GALILEO FREE FALL (1620)
- MILLIKAN OIL DROP (1909)
- NEWTON SPECTRAL DECOMPOSITION OF LIGHT (1665)
- YOUNG INTERFERENCE OF LIGHT (1801)
- CAVENDISH GRAVITY, TORSION (1798)
- ERASTOTHENES RADIUS OF THE EARTH (~ -300)
- GALILEI SCHIEFE EBENE (1620)
- RUTHERFORD SCATTERING EXPERIMENT (1911)
- FOUCAULT PENDULUM (1851)

- PHYSICS WORLD UMFRAGE 2002

DOUBLE SLIT EXPERIMENTS „SINGLE EVENTS“

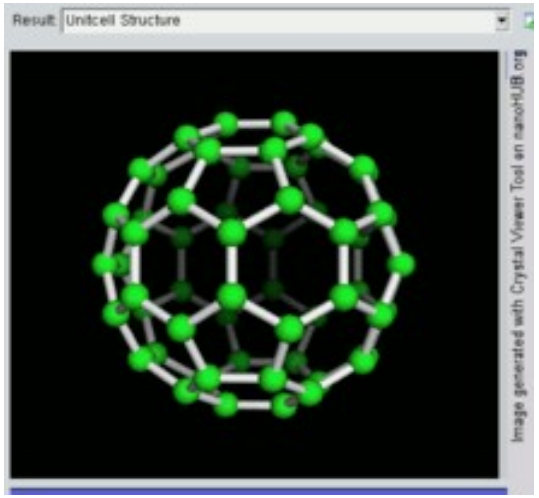
A. Tonomura et al.: American Journal of Physics 57, 117 (1989)

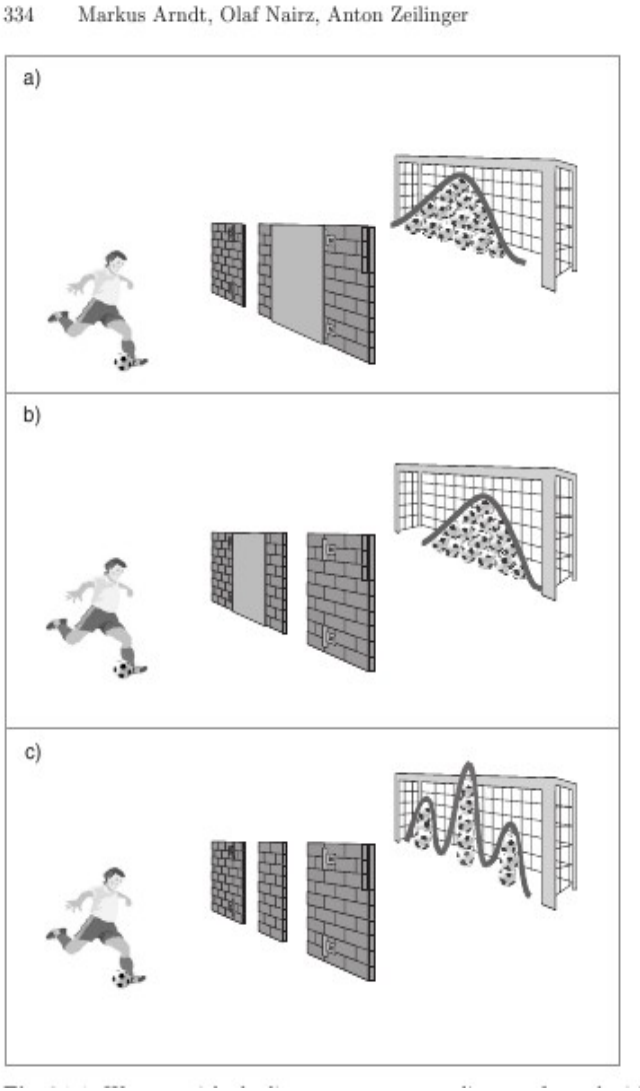




DOUBLE SLIT EXPERIMENTS WITH MACROMOLECULAR OBJECTS

- O. Nairz, M. Arndt, A. Zeilinger, Quantum interference experiments with large molecules, American Journal of Physics 71, 319-325 (2003)
- C 60, BUCKY BALLS





WEB-REFERENCE

- http://nobelprize.org/nobel_prizes/physics/articles/ekspong/

MATTER-WAVE DUALITY

THEORY COMBINING WAVE AND PARTICLE PROPERTIES

WAVE, QUANTUM MECHANICS
QUANTUM ELECTRODYNAMICS
QUANTUM FIELD THEORY
QUANTUM CHROMODYNAMICS,
STRING THEORY

WAVE FUNCTION SCHRÖDINGER EQUATION

$$\psi(x,t) = Ne^{i(kx-\omega t)}$$

- INTERPRETATION!

$$E = \hbar\omega = \frac{p^2}{2m} = \frac{\hbar^2 k^2}{2m}$$

$$\hbar\omega\psi(x,t) = \frac{\hbar^2 k^2}{2m}\psi(x,t)$$

$$i\hbar\frac{\partial}{\partial t}\psi(x,t) = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t)$$