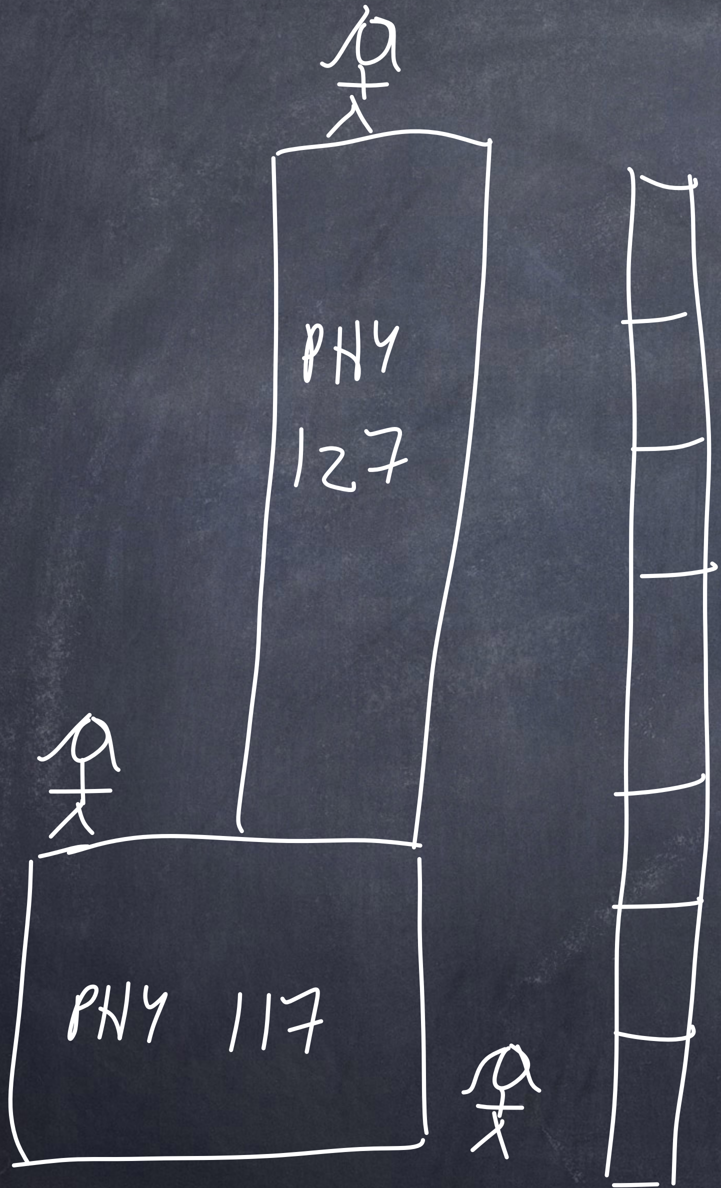
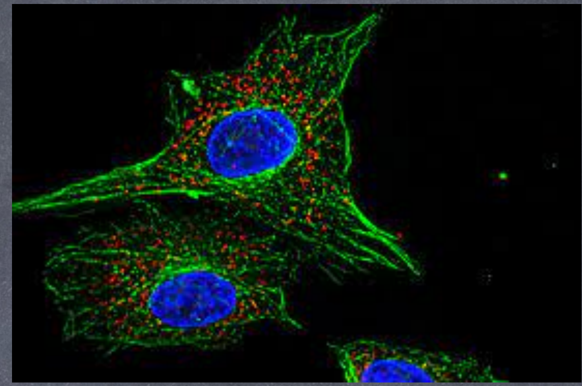
PHY127

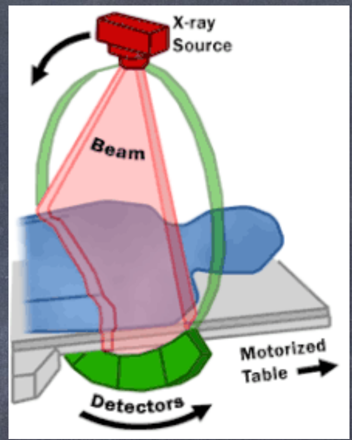
Prof. Ben Kilminster
Lecture 1
Feb. 23rd, 2024

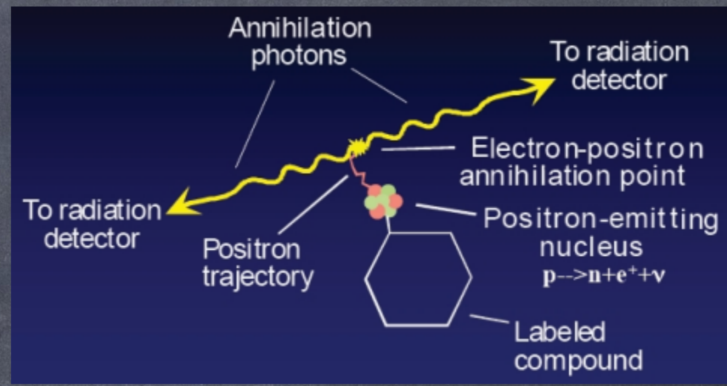
we will cover modern physics in a way that targets modern techniques in medical/biological/chemical research.

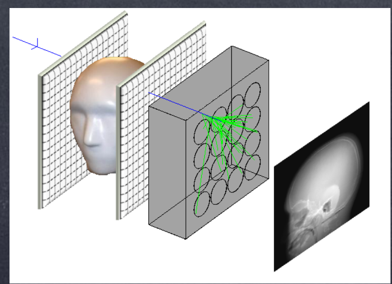
physics		bio-med
atomic physics		x-rays
nuclear physics		x-ray computed tomography
particle physics	⟹	CT scans
anti-matter		PET scans
radiation		NMR, MRI
relativity		medical diagnostics
quantum physics		treatment
		imaging

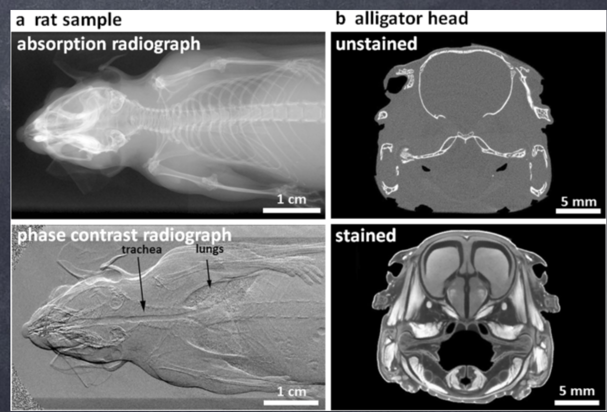

PHY 127
PHY 117




X-ray
Source
Beam
Motorized
Table
Detectors


Annihilation
photons
To radiation
detector
Electron-positron
annihilation point
To radiation
detector
Positron
trajectory
Positron-emitting
nucleus
p-->n+e⁺+ν
Labeled
compound




a rat sample
b alligator head
absorption radiograph
unstained
1 cm
5 mm
phase contrast radiograph
trachea
lungs
stained
1 cm
5 mm

PHY 127 FS 2023

Physics II for Biomed (Modern Physics)
Lecture : Fridays 8:00-10:00, Y15-G20

Professor Ben Kilminster (Email ben.kilminster@physik.uzh.ch)
Prof. K's office hours : 36-J-50 Fridays 11:45 – 13:00 (or by appointment)
Class page: https://www.physik.uzh.ch/de/lehre/PHY127/FS2024.html (user: physik-phy127, pass: maxwell5%)

Teachers assistants :
Frau Ruth Bründler (ruth.bruendler@physik.uzh.ch) (English/German speaking) (In charge of exercises & sessions)
Fanqiang Meng (fanqiang.meng@physik.uzh.ch) (English/Chinese speaking) In-class TA

Exercise session groups :

Group	Tuesday (Room)		Wednesday (Room)	
	13:00-15:45		13:00-15:45	
1	Haojie Geng	23-G-04	James O'Leary	23-G-04
2	Elias Carl	21-F-70	Roger Brunner	21-F-70
3	Guillem Cucurull Llovera	22-F-62	Philipp Maier	22-F-62
4	Loris Keller	22-F-68	Alessio Tassone	22-F-68
5	Yuliia Melnychuk	17-M-05	Florian Leitner	36-J-33
6	Jens Oppliger	27-H-35/36	Mariana Rajado	36-K-08

Alessio Tassone	atassone@student.ethz.ch
Elias Carl	elias.carl@protonmail.com
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Loris Keller	loris.keller@uzh.ch
Mariana Rajado Nunes Da Silva	mariana.rajado@physik.uzh.ch
Philipp Maier	philippemanueljan.maier@uzh.ch
Roger Brunner	rogbrunn@student.ethz.ch
Yuliia Melnychuk	yuliia.melnychuk@uzh.ch

References: Kilminster Physics 1 & 2 scripts (available on the course web site)
Introductory university physics text book. I use the following :
Tipler (Very good explanations, main text I follow)
Halliday & Resnick
Young & Freedman
(But these are all very similar. Find any one that explains physics well for you.)
For modern physics, I will point you to other online resources when relevant.

Assessments : **Please register on OLAT:** https://lms.uzh.ch/ This is how we send you assignments
Please log in to see if you can access the course. If not, check your UZH email is registered properly.

1) Exercise sessions: Tuesdays/Wednesdays, 13:00-16:00, starting Feb. 27th. TAs will explain homework exercises, answer questions, and go through additional exercises if time. TAs will keep an attendance list. **Note: You really have to go to the exercise sessions. This is where you learn how to solve problems. In your exams, you will have to solve similar problems. One problem will be almost the same.**

2) Written exercises: every 2 weeks. These will be assigned on Fridays, explained on the following Tuesday/Wednesday, and solutions will be presented the following week. First homework assigned Feb 24th.

3) Final exam. (date not known yet). UZH exam schedule

a. Exam style :

1. **Similar style to written exercises**
2. **Will be in German and English**
3. **Expect question from exercise sessions & relating to experiments shown in lecture**
4. **Formula sheet will be provided. (No private information allowed.)**

4) Grade : 100% final exam

Modern physics

PHY127 FS2024, Physics for Life Sciences 2

Schedule

Lecturer :	→ Prof. Ben Kilminster
Lectures (PHY127.1):	Friday, 08:00 - 09:45
Exercise sessions (PHY127.2):	Tuesday or Wednesday, 13:00 - 15:45 (First : 27th Feb 2024)
Office Hours	Fridays 11:45-13:00 at 36J50 or by email appointment

Lecturer

- Prof. Ben Kilminster
- → Webpage
- Office: Y36 J50
- Phone: +41 44 635 58 02
- Email: → ben.kilminster@physik.uzh.ch

References & texts

References for each lecture will be added below.

A document with german/english translations of common physics quantities, as well as a reminder of the units of such quantities is available here ⤓ PHY127-FS2024-helper.pdf (PDF, 95 KB)

The formula sheet for completing exercises and for the final exam:

- ⤓ PHY127_Formula_Sheet.pdf (PDF, 312 KB) (preliminary Feb. 20th, 2024)

The following can serve as a reference for the basic physics (from PHY 117)

- Ben Kilminster, Introductory Physics 1. ⤓ Kilminster-Intro-Physics-I.pdf (PDF, 5 MB)
- Ben Kilminster, Introductory Physics 2. ⤓ Kilminster-Intro-Physics-II.pdf (PDF, 4 MB)

Texts:

- Paul A. Tipler, Gene Mosca: Physics for scientists and engineers.
- Halliday & Resnick : Fundamentals of Physics.

Additional resources to help with mathematics.

- MHP: ⤓ Mathematische Hilfsmittel (PDF, 587 KB) (in german) derivatives, integrals, series expansions, statistics, vector algebra, coordinate transformations, tensors, ...)
- C.B. Lang und N. Pucker: *Mathematische Methoden der Physik,* Spektrum Verlag, Heidelberg und Berlin.

⤓ Formelsammlung Mittelschulphysik (PDF, 396 KB) is also useful for usage of basic formulas.

Exercises

Exercises are posted on OLAT every 2 weeks on Friday after lecture.

Exercise sessions in the following week will help you understand the terms and concepts of the exercises. Exercise sessions in the second week after the exercises are assigned will explain the solutions. It is expected that you will complete the exercises before this second exercise session.

There will be **no podcasts** of exercise classes.

Exam schedule

Exam guidelines :
Exams will be similar in style to the exercises. A formula sheet with all needed equations will be provided to you for use throughout the semester, and in the exams. We will provide you with paper and a calculator. The final exam will be printed in english and in german. The following are forbidden in exams :

- Any means of communication (mobile phones, smart watches, etc.)
- Any kind of calculator, laptop, or electronic storage device
- Any additional formula sheets or written notes.

Exam date: 28.06.2024, 10:00 - 12:00

Repeat exam date: 13.09.2024, 14:00 - 16:00

Grades

Your grade is based on the following assessments :

- 100% final examination

Attendance is expected and recorded for exercise sessions. The final examination will be composed of questions similar to those presented in the lectures and the weekly exercises.

Outline of course

The course will cover modern physics topics such as relativity, quantum physics, atomic, nuclear, and particle physics, radiation, particle-wave duality, particles interacting in matter, particle detection. These ideas will be used to explain the basics of modern radiation techniques for diagnostics and treatment, and such instruments as X-rays, CT scanners, PET scanners, NMR, MRI, etc.

Lecture information

Lecture schedule (12 lectures)	Topics	PDF of chalkboard	Additional resources
Week 1 (Feb. 23rd, 2024)	Intro, units, reminder of forces, and force balancing.		See additional resources linked above.

Physics I:

Introduction to physics

PHYSIK INSTITUT
UNIVERSITÄT ZÜRICH

Prof. Ben Kilminster

Introduction to mechanics, waves, and fluid dynamics

Contents

Physics II:
Introduction to physics

PHYSIK INSTITUT
UNIVERSITÄT ZÜRICH

PROF. BEN KILMINSTER

INTRODUCTION TO ELECTRICITY, MAGNETISM, ELECTROMAGNETISM, AND THERMODYNAMICS

Contents

Mathematische Hilfsmittel zur Physik I und II

mit ergänzenden Beispielen und Korrekturen, 15. Februar 2013

Physik - Institut Universität Zürich

Inhaltsverzeichnis

Formelblatt Physik HSGYM

4. April 2015, M. Lieberherr

Viele Gesetze und Informationen auf dieser Seite sollten von der Mittelschule her bekannt sein und angewendet werden können. Folgen Sie den braunen oder blauen Links für weitergehende Auskünfte oder dem Index.

Phys. Rechnen

Eine Grösse umfasst Zahlenwert und Einheit. Für gegebene und gesuchte Grössen werden Platzhalter eingeführt. Eine Schlussformel ist nach der gesuchten Grösse aufgelöst und enthält nur Variable für gegebene Grössen. Das Resultat hat ebenso viele signifikante Stellen wie die ungenaueste Ausgangsgrösse.

Mechanik

$\vec{v} = \frac{\Delta \vec{s}}{\Delta t}$

$1\,\text{m/s} = 3.6\,\text{km/h}$

$P = \frac{W}{\Delta t}$

$\eta = \frac{W_2}{W_1}$

$1\,\text{kWh} = 3.6\,\text{MJ}$

$\vec{p} = m\vec{v}$

$\vec{p}_1 + \vec{p}_2 + \cdots = const$

$\vec{F}_{res} = \frac{\Delta \vec{p}}{\Delta t}$

$\omega = \frac{2\pi}{T} = 2\pi f = \frac{v}{r}$

$a_z = \frac{v^2}{r} = r\omega^2$

$F_G = \frac{G m_1 m_2}{r^2}$

$G = 6.674 \cdot 10^{-11}\,\frac{\text{Nm}^2}{\text{kg}^2}$

$M = aF = rF\sin\alpha$

$a_1 F_1 = a_2 F_2$

$p = \frac{F_N}{A}$

$1\,\text{u} = 1.661 \cdot 10^{-27}\,\text{kg}$

$M = m/n$

$pV = nRT = Nk_BT$

$R = 8.314\,\text{J/(mol} \cdot \text{K)}$

$k_B = 1.381 \cdot 10^{-23}\,\text{J/K}$

$V_{mn} = 22.4 \cdot 10^{-3}\,\text{m}^3/\text{mol}$

$\frac{1}{2}mv^2 = \frac{3}{2}k_BT$

$\Delta U = Q + W + \ldots$

$pV^{\varkappa} = const$

$Q = mH$

$\eta = \frac{T_w - T_k}{T_w}$

Elektrizität

$e = 1.6022 \cdot 10^{-19}\,\text{C}$

$\Sigma Q_i = const$

$F_C = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q_1 Q_2}{r^2}$

$B = \frac{\mu_0 I}{2\pi r}$

$\mu_0 = 4\pi \cdot 10^{-7}\,\frac{\text{Vs}}{\text{Am}}$

$B = \frac{\mu_0 N I}{l}$

$U_{\text{ind}} = -\frac{d\Phi}{dt}$

$\Phi = AB_\perp$

$u(t) = \hat{u}\cos(\omega t)$

$U_{\text{eff}} = \frac{\hat{u}}{\sqrt{2}}$

Schwingungen/Wellen

$y(t) = \hat{y}\sin(\omega t + \varphi_0)$

$T = 2\pi\sqrt{m/D}$

$T = 2\pi\sqrt{l/g}$

$\alpha_r = \alpha_1$

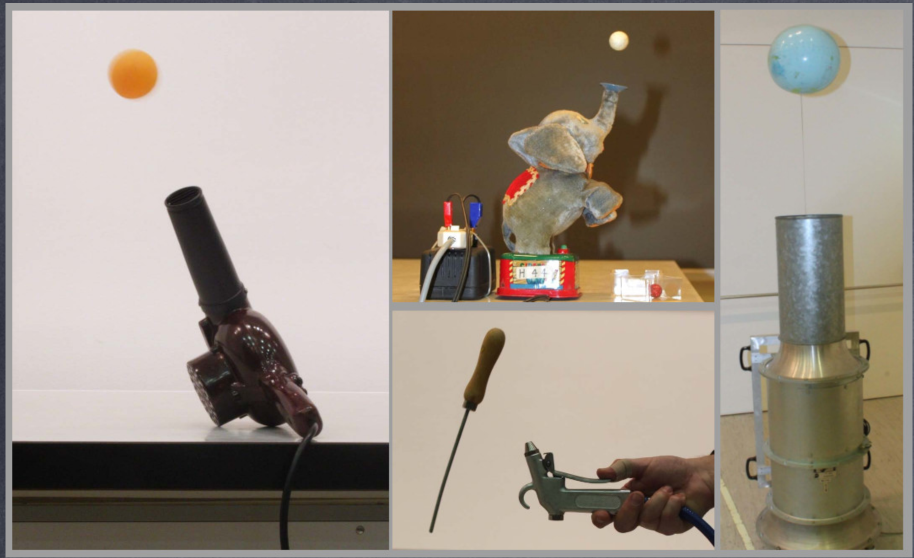
$n_1 \sin\alpha_1 = n_2 \sin\alpha_2$

Lecture schedule (12 lectures)	Topics	PDF of chalkboard	Additional resources
Week 1 (Feb. 23rd, 2024)	Intro, units, reminder of forces, and force balancing.		See additional resources linked above.
Week 2 (Mar. 1st, 2024)	**Electromagnetic radiation.**		See PHY121 script, chapters 13,18,&19 for more on waves, the power of heat of EM radiation.
Week 3 (Mar. 8th, 2024)	**But are photons particles or waves ?**		See Thornton & Rex, "Modern Physics", chapter 3, available online.
Week 4 (Mar. 15th, 2024)	**Waves, standing waves, probabilities**		See Script 1 chapter 12 on harmonic oscillators, and script 2 chapter 12 on waves.
Week 5 (Mar. 22nd, 2024)	**Wave-particle duality, wave packets, uncertainty principle, Schroedinger wave equation**		See script sectipon 12.1.2 & 12.1.3 for small-angle approximation, more on waves in chapter 13. Wave-diffraction (GIF, 592 KB) , Wave-diffraction-big-aperture (GIF, 276 KB) , wave-packet (GIF, 3 MB) , group-and-phase-velocity (GIF, 1 MB)
Week 6 (Apr. 12th, 2024)	The quantum nature of electrons in an atom, and emitted light. Standing waves. Particle in a 3D box.		Videos shown on standing waves on a 2D drum: StandingWave-drum-1
Week 7 (Apr. 19th, 2024)	**Hydrogen atom in 3D, with 3 quantum numbers. Angular momentum. Standing waves.**		For more information, see script 1 on angular momentum, and script 2 on magnetic moment.
Week 8 (Apr. 26th, 2024)	**Many-electron atoms, charge screening, X-rays, Bremsstrahlung, Characteristic X-rays, Thomson scattering, Compton effect, Bragg's law**		
Week 9 (May 3rd, 2024)	**X-ray penetration, attenuation, radiation dose, exposure dose, biological effects of radiation, CT scans with X-rays, pair production, pair annihilation, PET scans**		
Week 10 (May 10th, 2024)	**microCT, nanoCT, phase-contrast imaging, Fresnel plate focusing, synchrotron accelerators, X-ray synchrotron imaging, X-ray free electron laser imaging**		See videos in videopodcast. (No videos available in PDF)
Week 11 (May 17th, 2024)	**Angular momentum, precession of spinning object in gravity, precession of magnet in magnetic field, nuclear magnetic moment, nuclear magnetic resonance**		
Week 12 (May 24th, 2024)	**nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI), strong nuclear force, nuclear structure**		More on solenoids (sec. 8.2), and induced currents due to changing magnetic moments (sec. 8.3) in script.
Week 13 (May 31st, 2024)	**Nuclear stability, nuclear decay, alpha, beta, gamma radiation. Decay series chains. Half lives. Bethe-Bloch energy loss. Dose delivered. Nuclear fission. Nuclear fusion.**		

PHY 127 Physics Terms helper Prof. Ben Kilminster

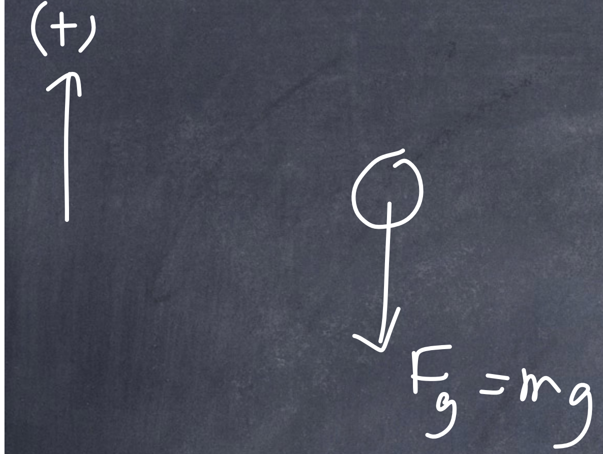
physical quantity (SI base units in blue) (radiation physics units)	Deutsch	Symbol	SI unit	Simplified Formula to help with units	in other SI units	typical units in radiation physics	conversions
Length	Länge	ℓ	meter = m				
time	Zeit	t	second = s				
velocity	Geschwindigkeit	v	m/s			c=~3E8 m/s	
acceleration	Beschleunigung	a	m/s^2				
mass	Masse	m	kilogram = kg			$1eV/c^2$	$1eV/c^2$ = 1.78E-36 kg
momentum	Impuls	p	kg*m/s	p=mv			
force	Kraft	F	Newton = N	F = ma	1N = $kg*m/s^2$		
torque	Drehmoment	τ	N*m	$\tau = rF \sin\theta$	$kg*m^2/s^2$		
energy, work	Energie, Arbeit	E, W	Joule = J	W = Fx	1J = $kg*m^2/s^2$	1eV	1eV = 1.602E-19J
power	Leistung	P	Watt = W	P = E/t	1W = $kg*m^2/s$		
pressure	Druck	P	Pascal = Pa	P = F/area	1Pa=$1N/m^2$		
Electrical charge	Elektrische Ladung	q	Coulomb = C			e = electron charge	1e = 1.602E-19C
Electrical current	Stromstärke	I	Ampere = Amp = A	I = q/t	1A=1C/s		
Electric potential	Elektrische Spannung	V or ϕ	Volt = V	Power = IV	1V = 1W/A		
Electric field	Elektrisches Feld	E	N/C = V/m				
Magnetic field	Magnetische Flussdichte	B	Tesla = T	F=BIℓ	1T=1N/(A*m)		
Resistance	Elektrischer Widerstand	R	Ohms = Ω	V = IR	1Ω = 1V/A		
Capacitance	Elektrische Kapazität	C	Farad = F	C=q/V	1F = 1C/V		
Temperature	Temperatur	T	Kelvin = K				
amount of substance	Stoffmenge	N	Mol				
luminous intensity	Lichtstärke	I_v	Candela = cd				
radioactivity	Radioaktivität	A_{Bq}	Becquerel = Bq		1/s		
Absorbed dose	Energiedosis	D_T	Gray = Gy		m^2/s^2 = J/kg		
Equivalent dose	Äquivalentdosis	H_T	Sievert = Sv		m^2/s^2 = J/kg		

Goal today: introduce physics principles to understand charge quantization, so that we can learn that electrons are particles with a fixed mass and charge



Which forces are at play here?

Newton's second law: $\Sigma \bar{F} = m\bar{a}$



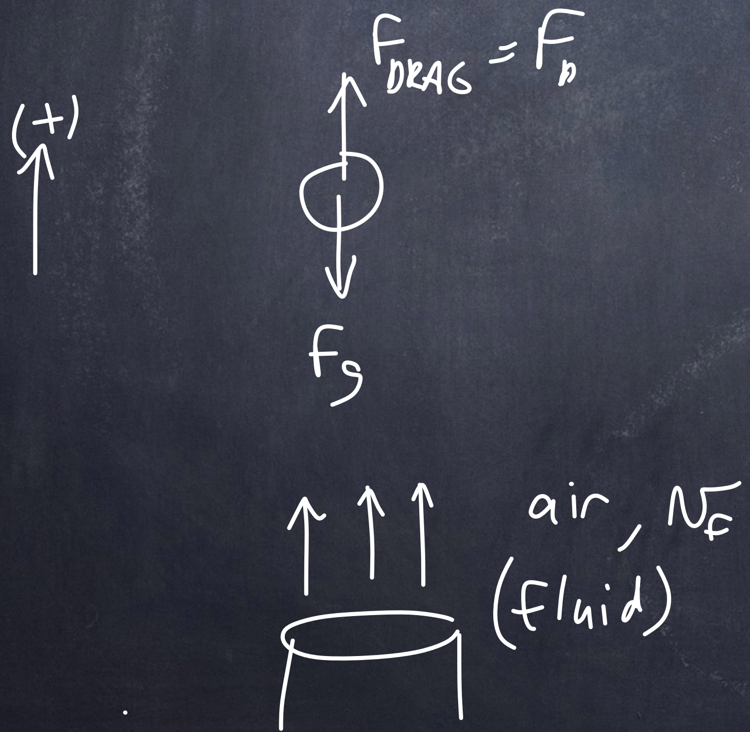
falling ball:

$$\Sigma \bar{F} = -F_g = -mg = ma$$

$$a = -g$$

$$\bar{a} = -\bar{g} \qquad g = 9.8\ m/s^2$$

Experiment: ball held up by a column of air



$$F_{DRAG} = F_D = -b v_b$$

v_b: velocity of ball with respect to air

$$\boxed{b = 6\pi\eta r}$$

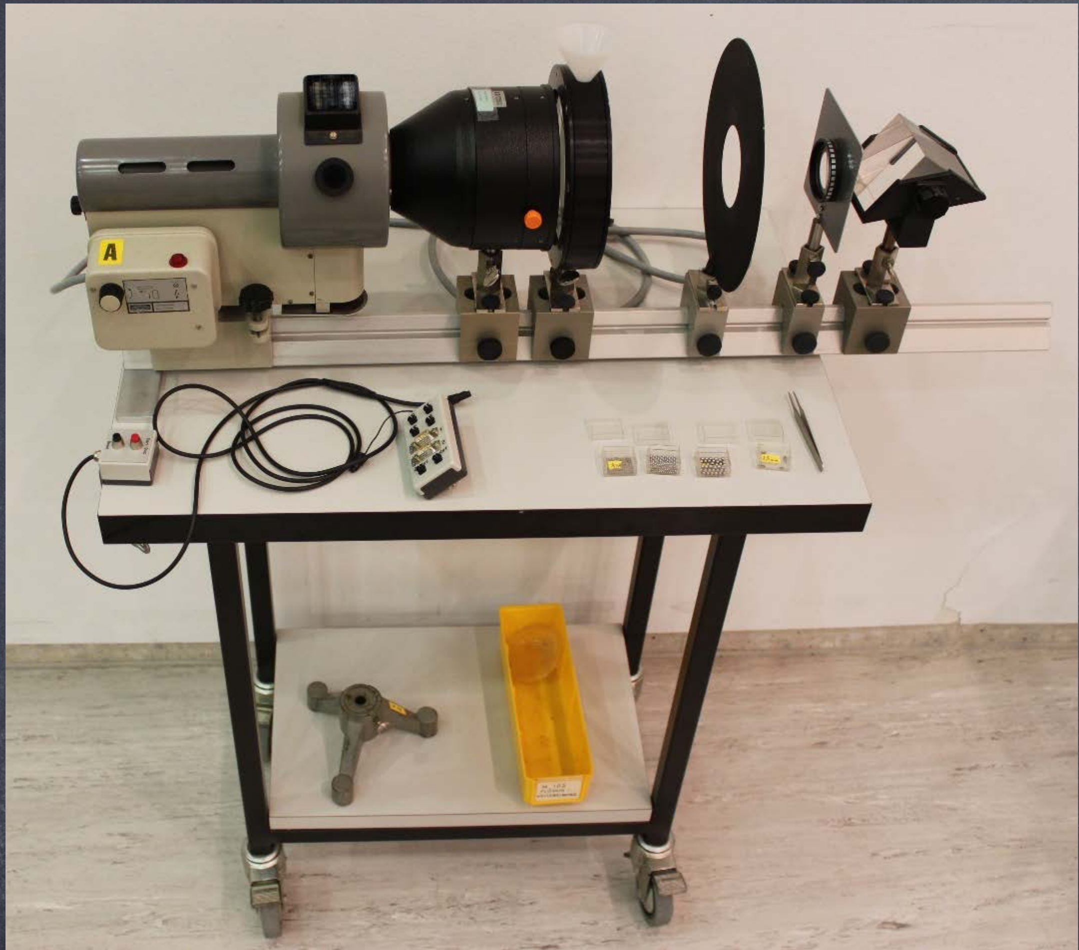
Stokes' Law

η: viscosity of fluid

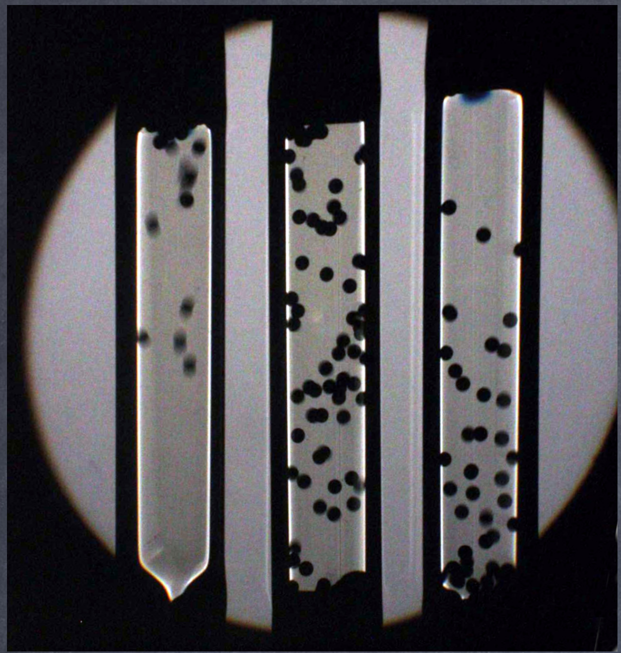
r: radius of the ball

$$\Sigma F = F_D - F_g = ma = 0$$

$$F_D = F_g$$



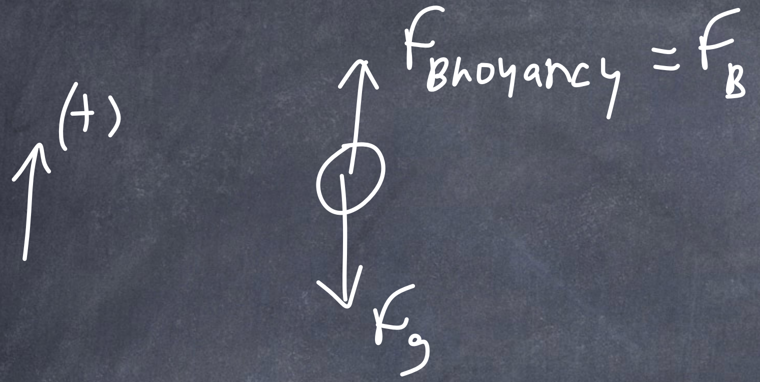
Which forces are at play here?



Which forces are at play here?

will it float?

Experiment 2: buoyancy



when ball is suspended,

$$\Sigma F = F_B - F_g = m\cancel{a} = 0 \quad (a = 0 \text{ not moving})$$

$$F_B = F_g$$

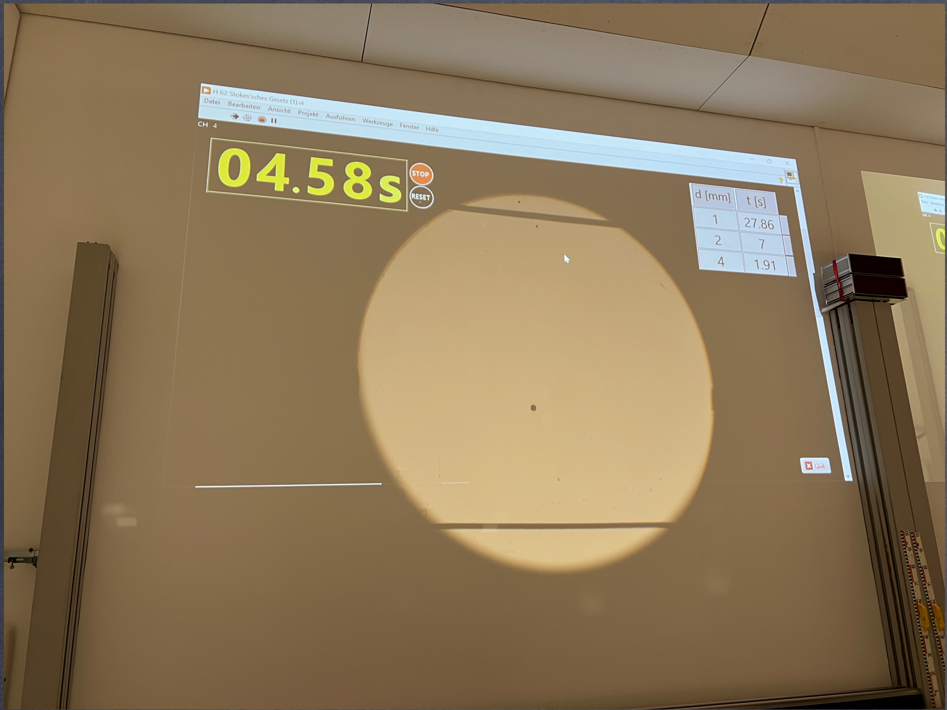
F_B : weight of fluid being displaced by the ball

Archimedes' principle: There is a buoyant force (upward) on an object that is immersed in a fluid.

$$F_B = m_f \, g$$

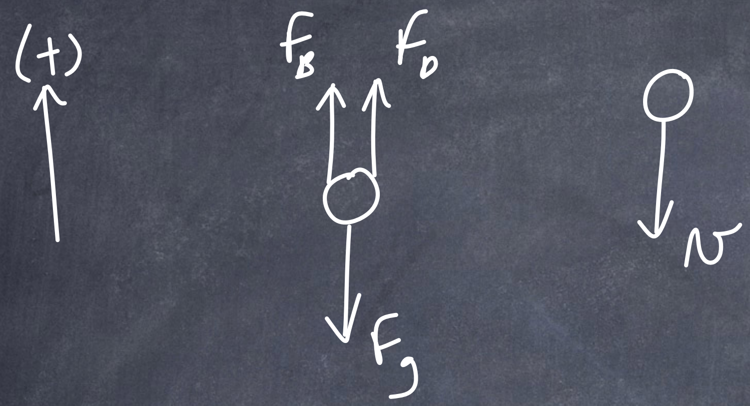
density of fluid, $\sigma = \dfrac{m_f}{\text{Volume}}$

m_f = density * volume



what forces are at play?

Experiment 3: Buoyancy, drag force, gravity



Ball reaches a constant velocity (terminal velocity) when forces balance.

$$\sum F = F_B + F_D - F_g = m\vec{a}^{\,0} = 0$$

ball: density $= \rho = \dfrac{m}{V}$ $\quad m = \rho V$

$$F_g = mg = \rho V g = \rho\left(\tfrac{4}{3}\pi r^3\right) g$$

$$F_B = m_f g = \sigma V g = \sigma\left(\tfrac{4}{3}\pi r^3\right) g$$

(m_f ↑ fluid; σ ↑ density of fluid)

$$F_D = +bv = (6\pi\eta r)\, v_t$$

(v_t ↑ terminal velocity)

At equilibrium, $F_B + F_D - F_g = 0$

$$\sigma\left(\tfrac{4}{3}\pi r^3\right)g + (6\pi\eta r)v_t - \rho\left(\tfrac{4}{3}\pi r^3\right)g = 0$$

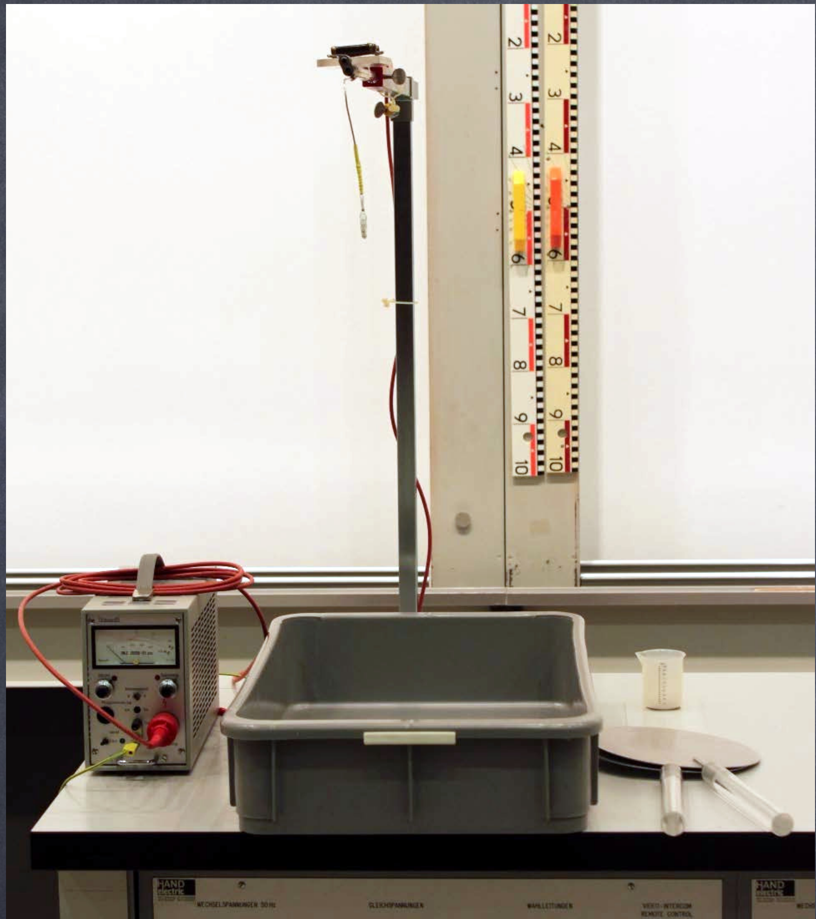
$$v_t = \frac{(\rho-\sigma)\left(\tfrac{4}{3}\pi r^{\not{3}\,2}\right)g}{6\pi\eta \not{r}}$$

we see : $v_t \propto r^2$

The bigger the ball, the faster the ball

Approximate a skier as a ball.

Is it faster to be a big skier or a small skier ?

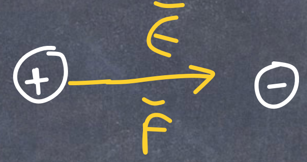


Electric charge

Which forces are at play here?

Experiment 4: add electricity (tennis)

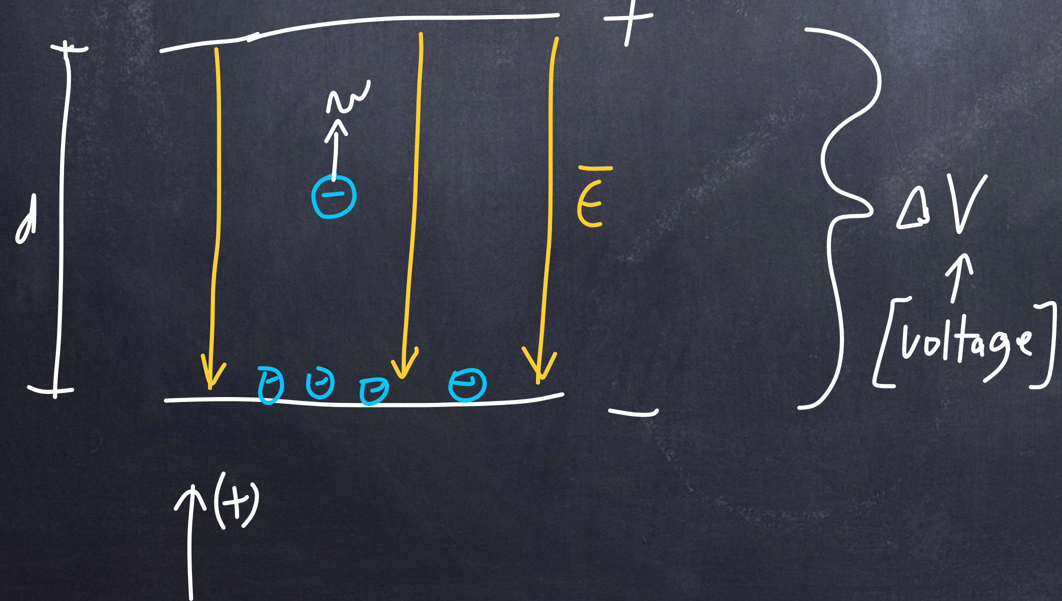
→ bubbles can be charged electrically, with electric potential, and there is an electric force, F_E.



$\bar{F} = q\bar{E}$

($\bar{E}$ points in the direction a (+) charge would go)

Experiment 5: tiny glass balls in an electric field filled with oil



$|\bar{E}| = \frac{\Delta V}{d}$

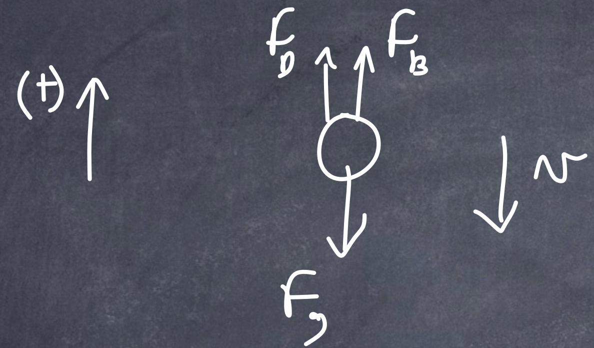
$\bar{F}_E = q\bar{E}$

q: (−) charge on ball

$\bar{E}$: (−) direction

$\bar{F}_E$ is in (+) direction

case 1: ball falling in fluid, no electric field

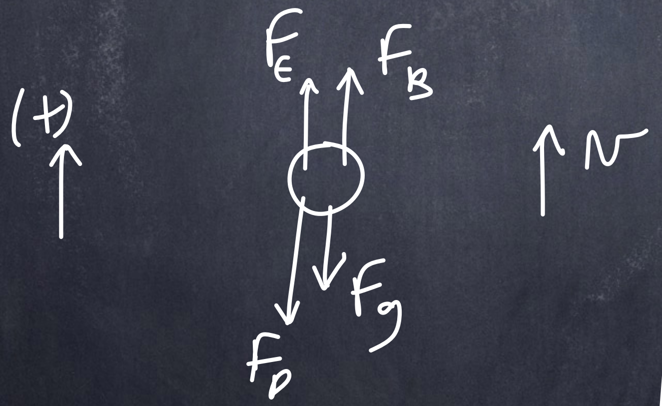


At equilibrium (no acceleration), ball has a terminal velocity (constant v_t)

$$F_D + F_B - F_g = 0$$

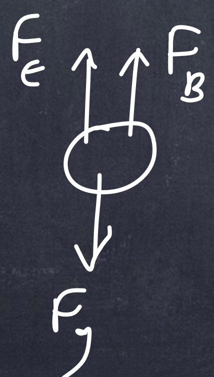
we could measure v_t, could determine r very precisely

case 2: we have electric field, balls go up.



$$\Sigma F = F_E + F_B - F_g - F_D = m\cancel{a}^{0} = 0$$

case 3: balls are suspended in an $\vec{E}$-field



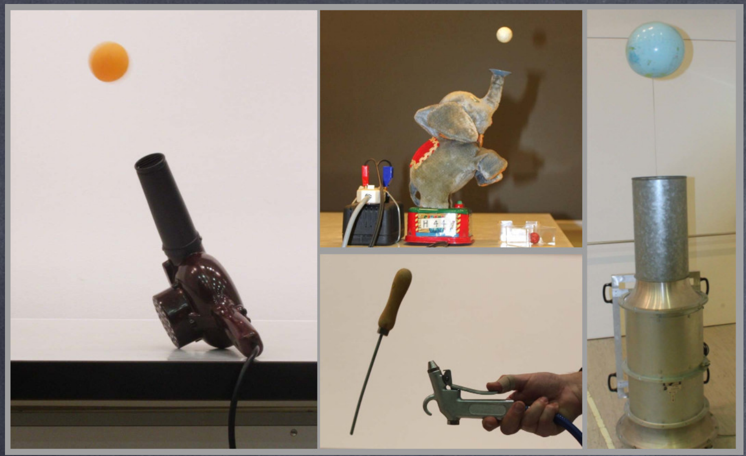
$v = 0$, so no F_D

$$\Sigma F = F_E + F_B - F_g = m\cancel{a}^{0} = 0$$

If time, in-class survey …

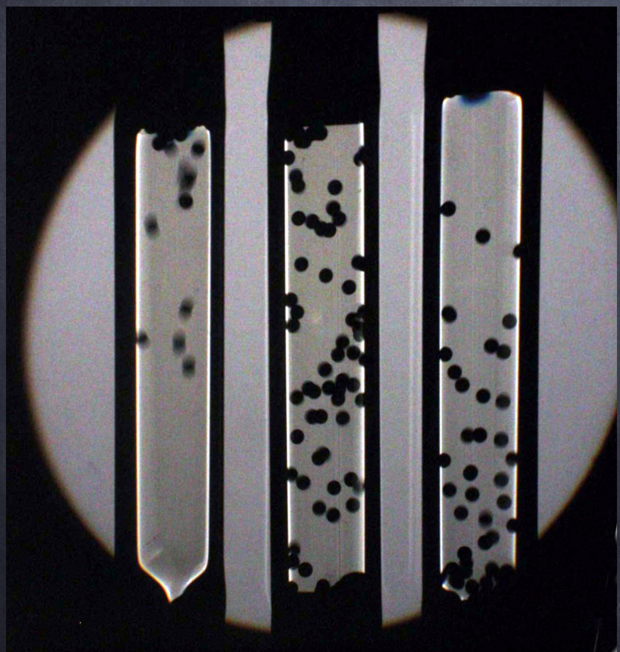
https://lms.uzh.ch/

Survey

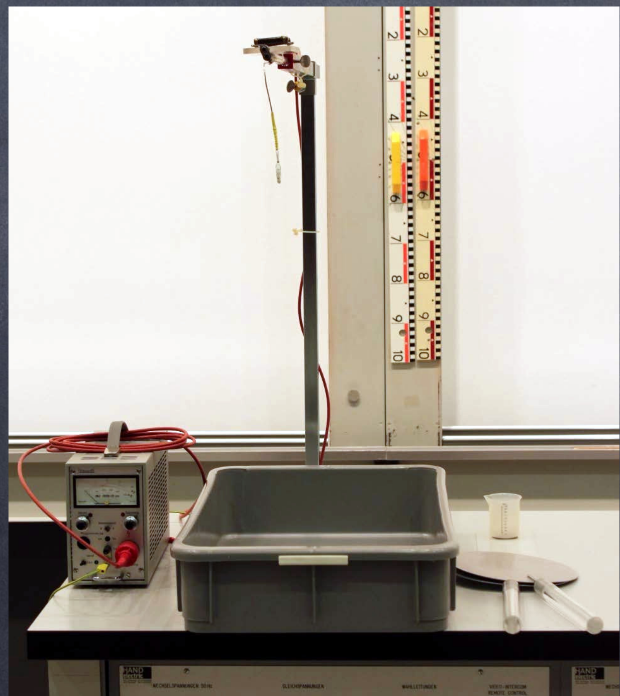


H44

H62



H108



ES36

ES38