Speed of light (8 points) E1

Physics in Denmark

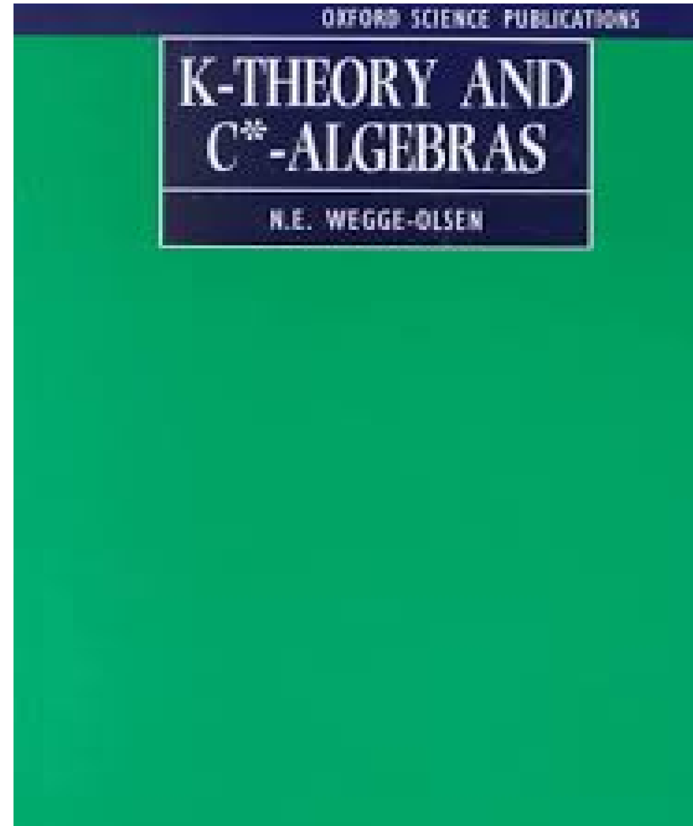
Any known Danish names?

Niels

Niels Hartling

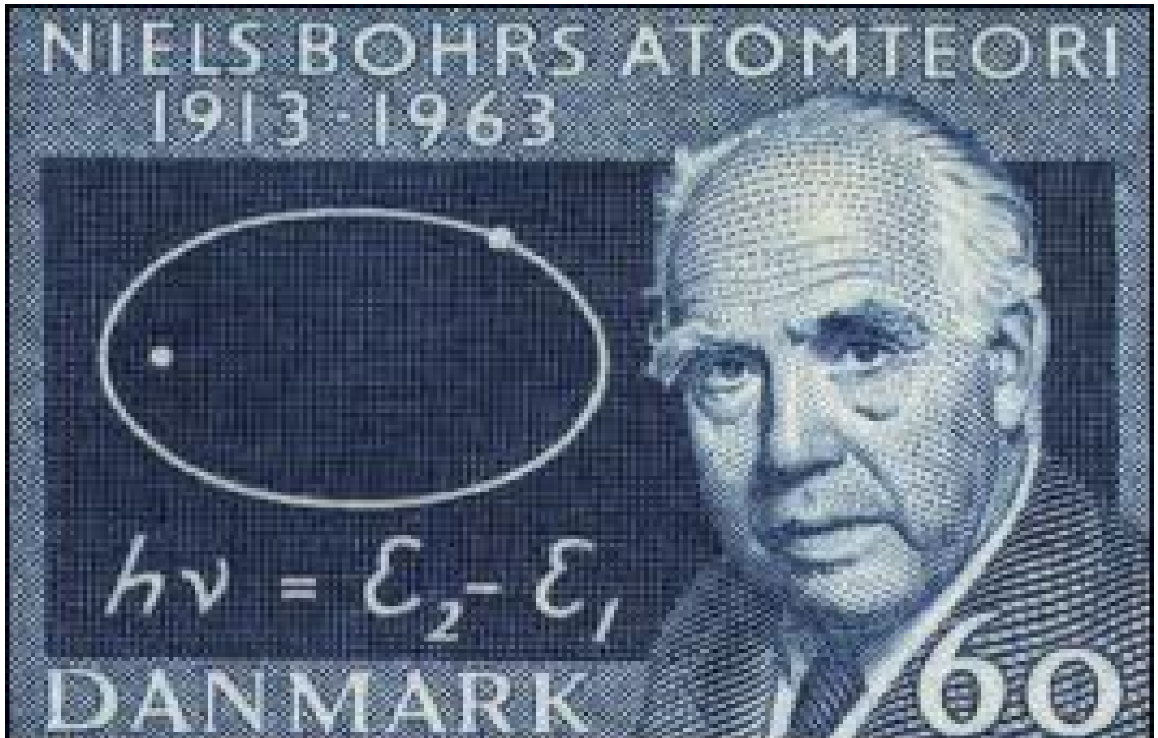
Niels Østergaard

Niels Erik Wegge



Niels Henning Ørsted Pedersen

Niels Bohr



We appreciate that you have studied the quantum model for hydrogen of Niels Bohr from 1913

But it would be too obvious.

Hydrogen is only in the logo

International Physics Olympiad 2013

IPhO

44th

Copenhagen Denmark **7-15 July 2013**

Denmark applies for being appointed as IPhO host country in 2075 to celebrate the [redacted] anniversary for [redacted] by [redacted]

So what could be the topic for the experimental problem?

What other names do we have?

Christian

Niels Christian Hartling

Niels Christian Jensen

Christian
Thune Jacobsen

Christian
Petresch

Christian IV

Prince Christian

Hans Christian Varnæs

Hans Christian Andersen

Hans Christian Ørsted

Ørsted founded DTU
Ørsted discovered EM
Ørsted dropped further research on electromagnetism
Other scientists took over and electromagnetism left Denmark

So let us look for other names

Ole

Ole Trinhammer

The mass ratio and the model. – The ratio we get between the electron mass m_e and the proton mass m_p is

$$\frac{m_e}{m_p} = \frac{\alpha}{\pi}\frac{1}{\mathrm{E}}, \tag{1}$$

where $\alpha = e^2/(\hbar 4\pi\epsilon_0)$ is the fine-structure constant [1] and $\mathrm{E} = E/\Lambda$ is the dimensionless ground-state eigenvalue of a reinterpreted lattice gauge theory Kogut-Susskind Hamiltonian [2],

$$\frac{\hbar c}{a}\left[-\frac{1}{2}\Delta + \frac{1}{2}\mathrm{Tr}\chi^2\right]\Psi(u) = E\Psi(u). \tag{2}$$

Denmark applies for being appointed as IPhO host country in 2075 to celebrate the [redacted] anniversary for [redacted] by [redacted]

Denmark applies for being appointed as IPhO host country in 2075 to celebrate the 400 anniversary for [redacted] by [redacted]

Ole Rømer 1644-1710

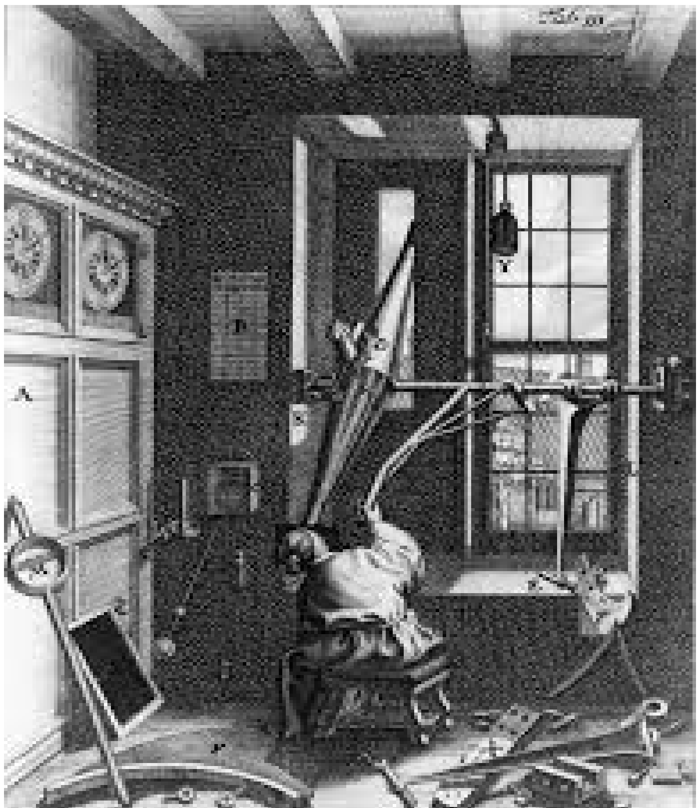
Latin: Olaus Roemer

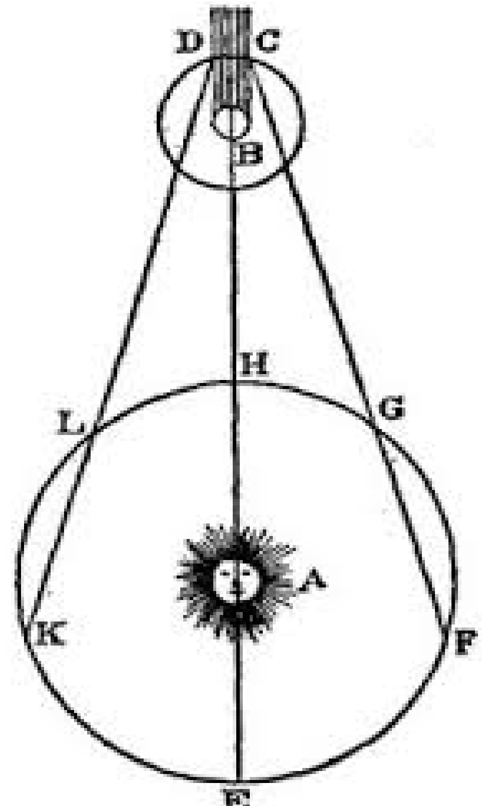
Denmark applies for being appointed as IPhO host country in 2075 to celebrate the 400 anniversary for [redacted] by Ole Rømer

Denmark applies for being appointed as IPhO host country in 2075 to celebrate the 400 anniversary for measurement of the speed of light by Ole Rømer

Speed of light 1676

$$c = 2.14 \cdot 10^8 \ \mathrm{m/s}$$





Fundamental Physical Constants

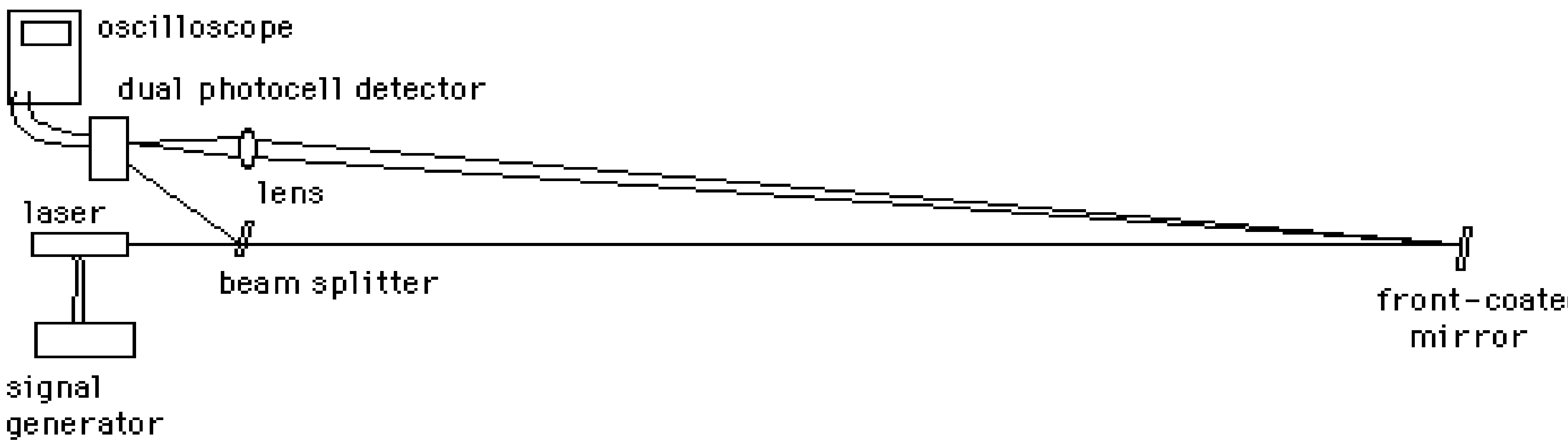
1) *c* speed of light: Ole Rømer 1676, Bradley 1726

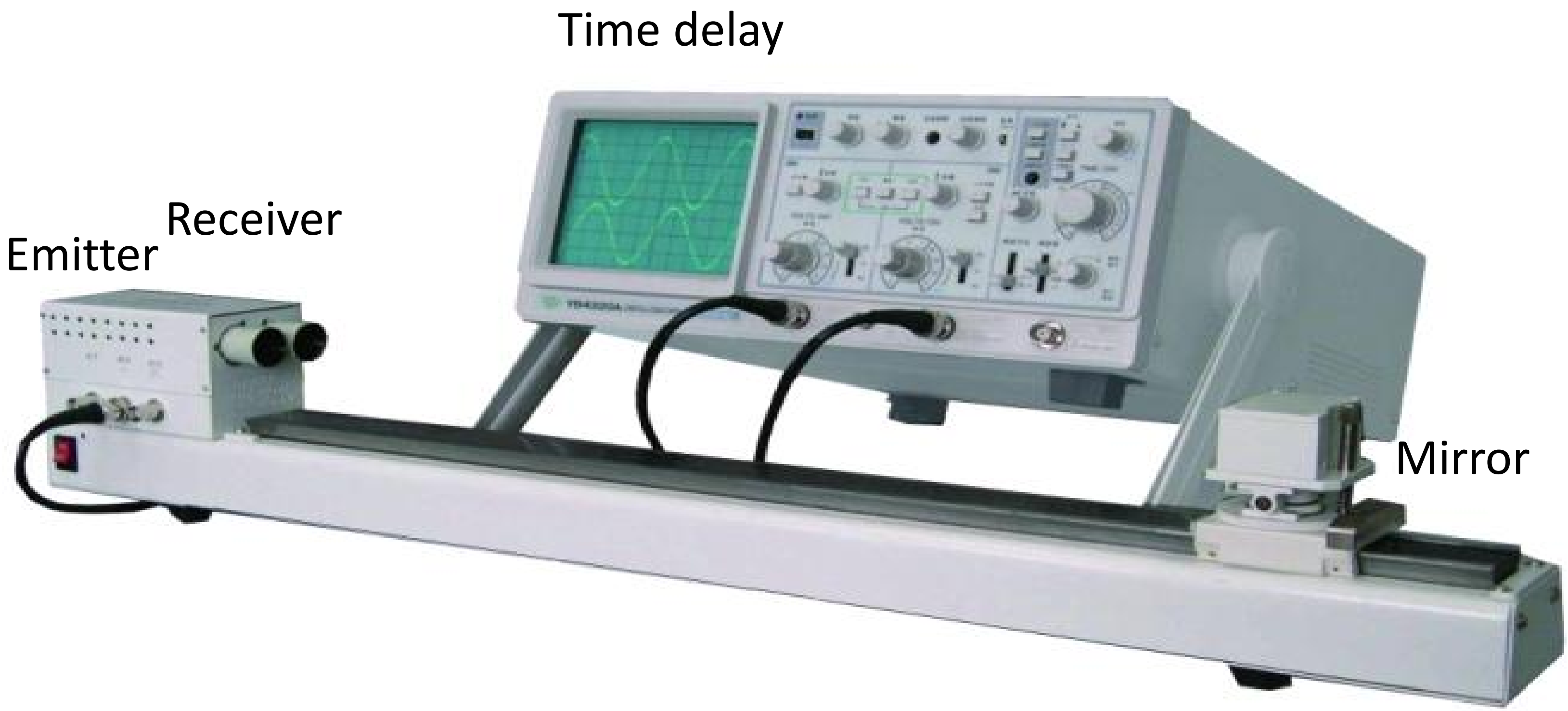
2) *G* gravitational constant: Cavendish 1798

3,4,5,6…) k_{B}, N_{A}, *h*, *e/m*, *e*… about 100 years later…

Year	Name	Method	Value of c / [km/s]
1675	Ole Rømer	Moons of Jupiter	214,000 (Huygens, AU)
1729	Bradley	Stellar aberration	301,000
1849	Fizeau	Toothed wheel	315,000
1862	Foucault	Rotating mirror	298,000±500
1865	Maxwell	EM constants	$\left(\sqrt{\epsilon_0\mu_0}\right)^{-1}$
1879	Michelson	Rotating mirror	299,910±50
1905	Einstein	Postulate	c
1907	Rosa, Dorsey	EM constants	299,710±30
1926	Michelson	Rotating mirror	299,796±4
1950	Gordon-Smith	Cavity resonator	299,792.5±3.0
1958	Froome	Radio interferometry	299,792.5±0.1
1972	Evenson	Laser interferometry	299,792.456±0.001
1983	17th CGPM	Definition	299,792.458

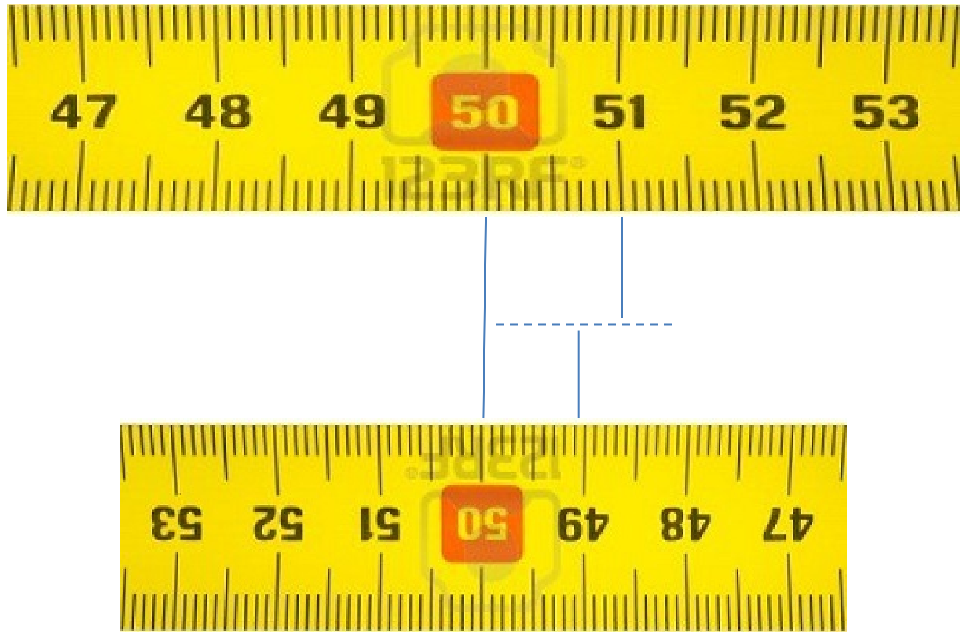
Two-way measurement of *c*




Time delay
Receiver
Emitter
Mirror

Only two-way measurements of the speed of light can be performed. *c* is the average value. Einstein postulates that it goes in both direction with the same speed. It can't be verified experimentally. That is why it is a postulate

What is 1 m?


47
48
49
50
51
52
53

Laser Distance Meter (LDM)

The laser distance meter seen from the front end:

A: Receiver: Lens for the telescope focused on the laser dot.

B: Emitter: Do not look into the laser beam!

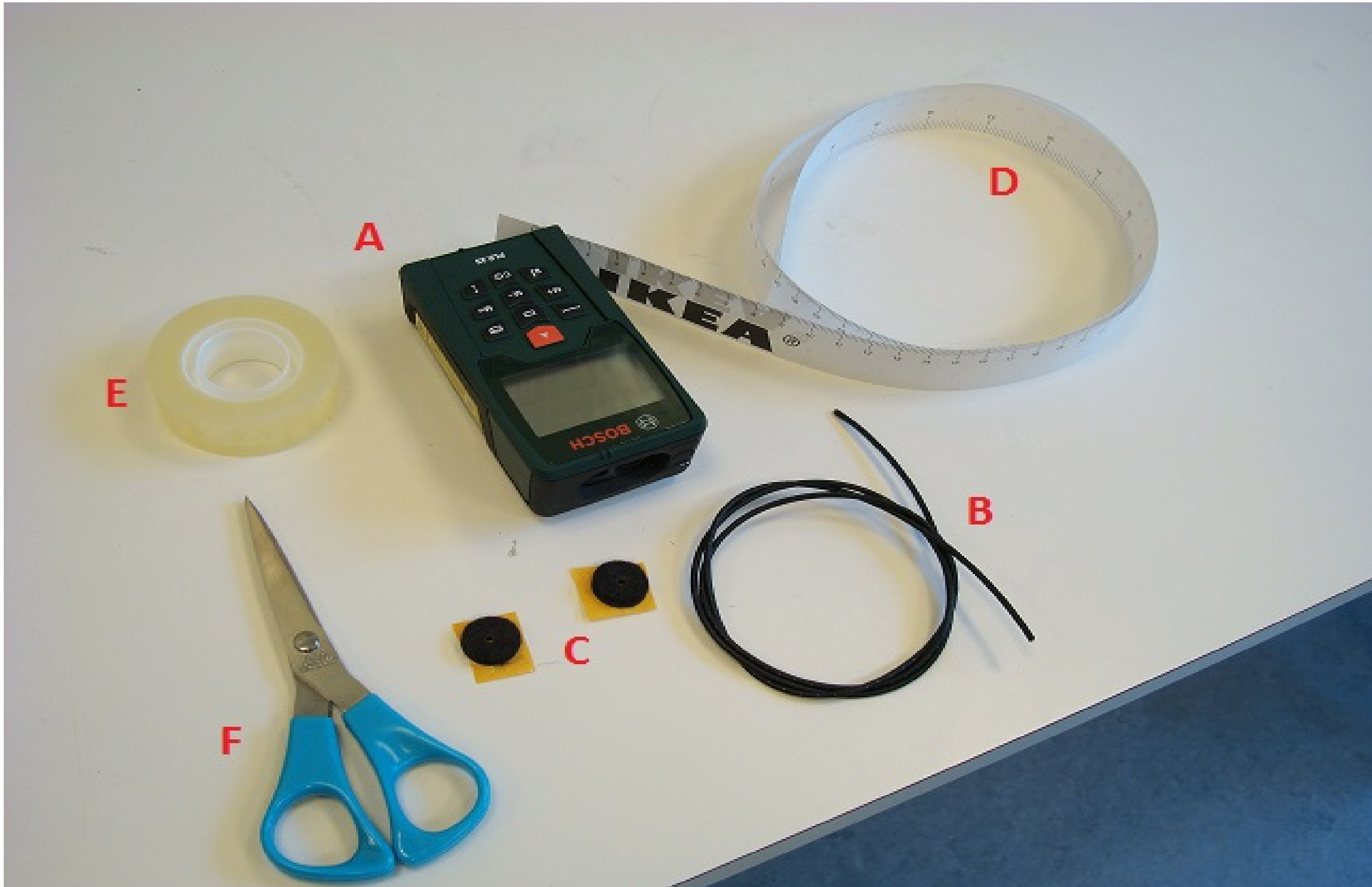
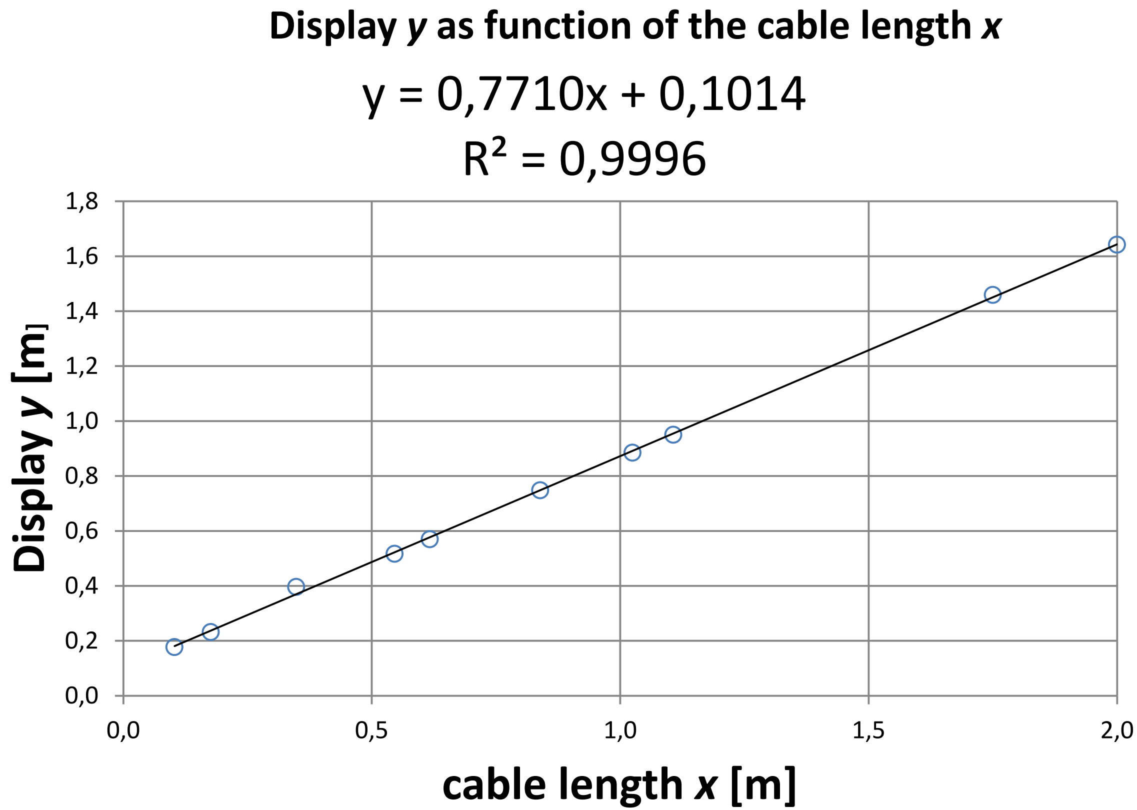

A
D
E
B
C
F

Diagram of a fiber optic cable.


BOSCH
0.416

x	*y*
m	m
0,103	0,177
0,176	0,232
0,348	0,396
0,546	0,517
0,617	0,570
0,839	0,748
1,025	0,885
1,107	0,950
1,750	1,459
2,000	1,642



The refractive index is twice the gradient of the line

$$n_{\text{co}} = 2 \cdot 0,7710 = 1,542$$

The reason for that is that the travel time for a light pulse

$$t = \frac{x}{v_{\text{co}}} = \frac{x n_{\text{co}}}{c}$$

The display will therefore show

$$y = \frac{1}{2} ct + k \Leftrightarrow y = \frac{1}{2} n_{\text{co}} x + k$$

Lysets fart i lyslederkablet er $v_{\text{co}} = \frac{c}{n_{\text{co}}} = 1,95 \cdot 10^{8}\,\frac{\text{m}}{\text{s}}$

Don’t worry about:

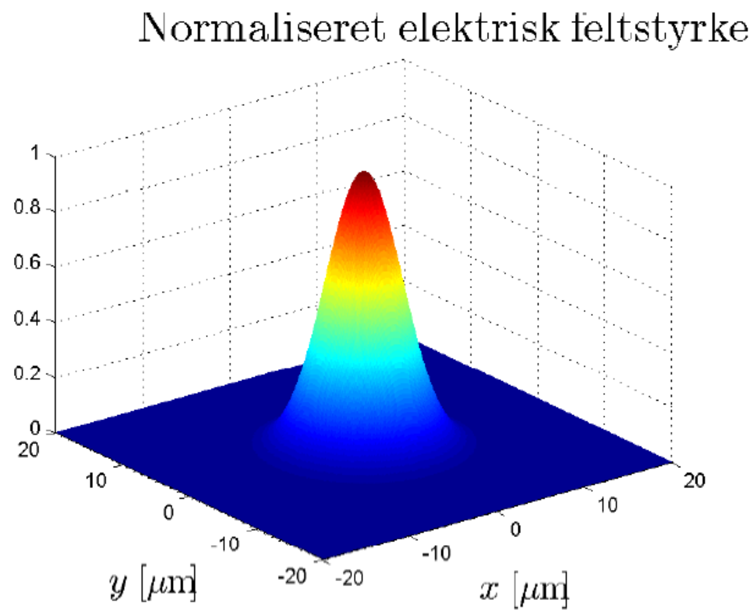
*Photonics

*Multi-mode/single-mode cable

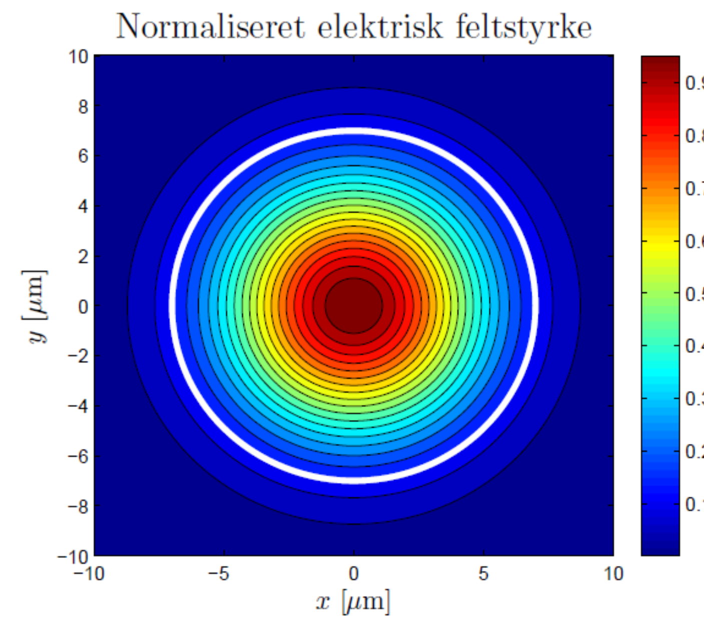
*Group velocity and phase velocity

*Cutting the fiber cable with scissors

Single mode

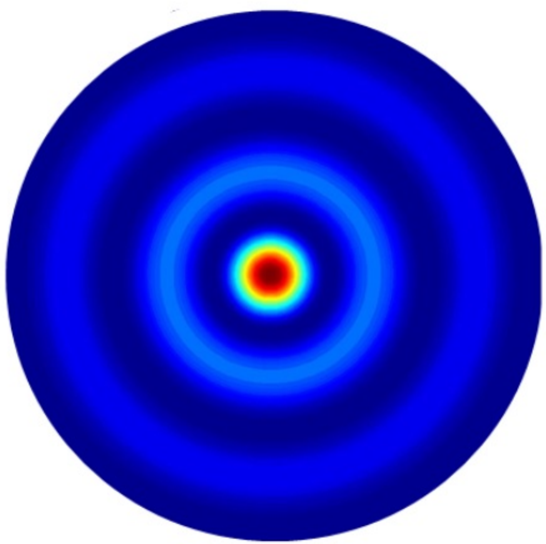


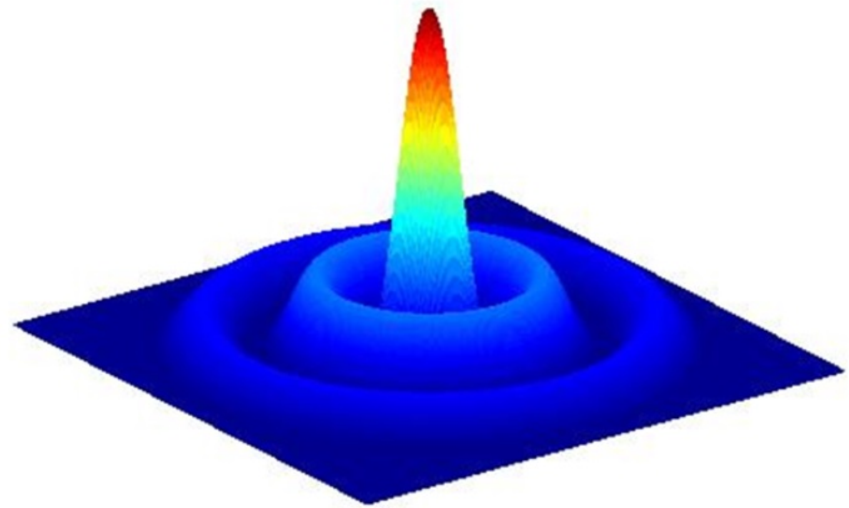
Normaliseret elektrisk feltstyrke
1
0.8
0.6
0.4
0.2
0
20
10
0
-10
-20
-20
-10
0
10
20
y [μm]
x [μm]



Normaliseret elektrisk feltstyrke
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−5
0
5
10
y [μm]
x [μm]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

Multi mode





In a thin waveguide of diameter *a*

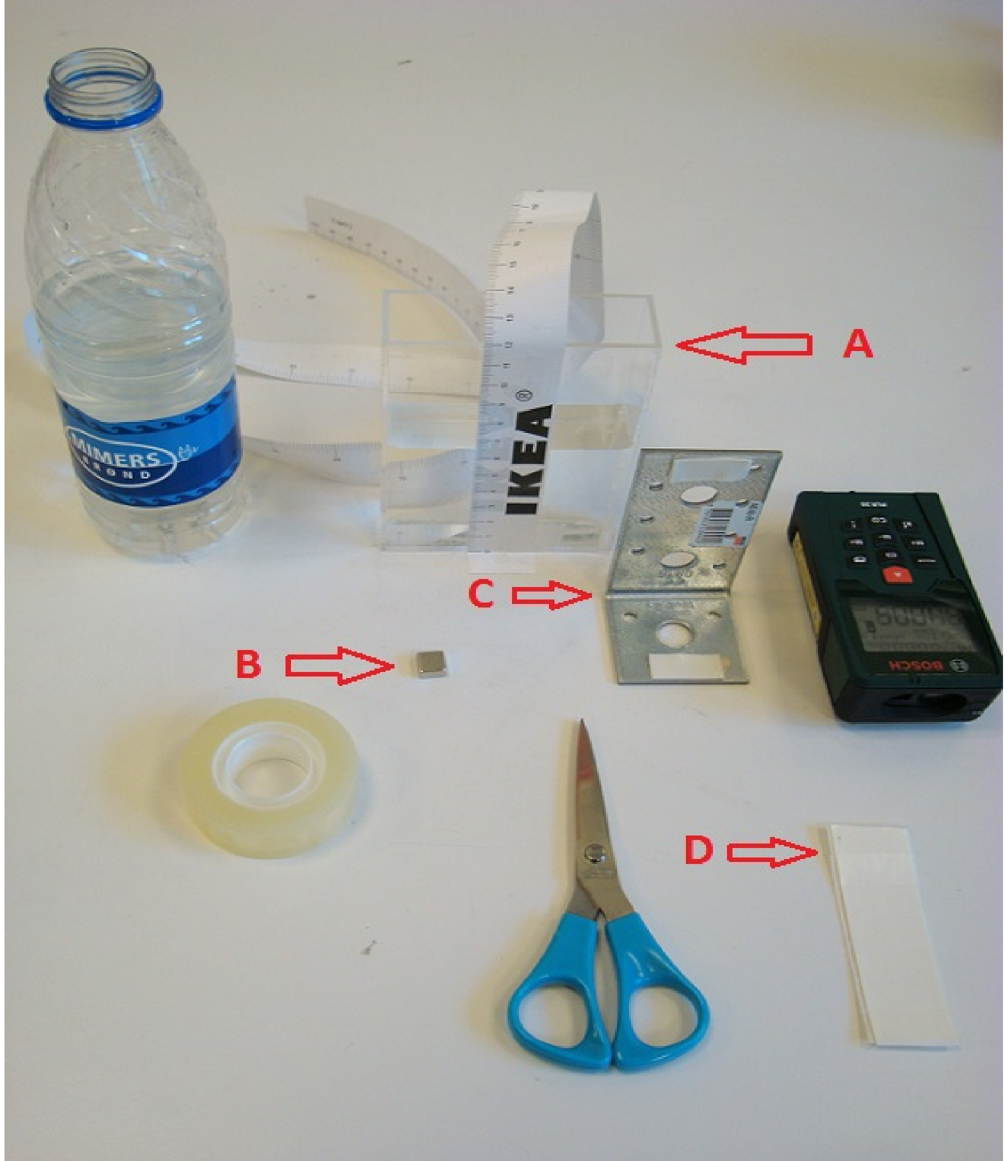
$$\frac{v_{\text{phase}}}{v_{\text{group}}} = \left(1 - \left(\frac{\lambda}{2an_{\text{co}}}\right)^2\right)^{-\frac{1}{2}}$$

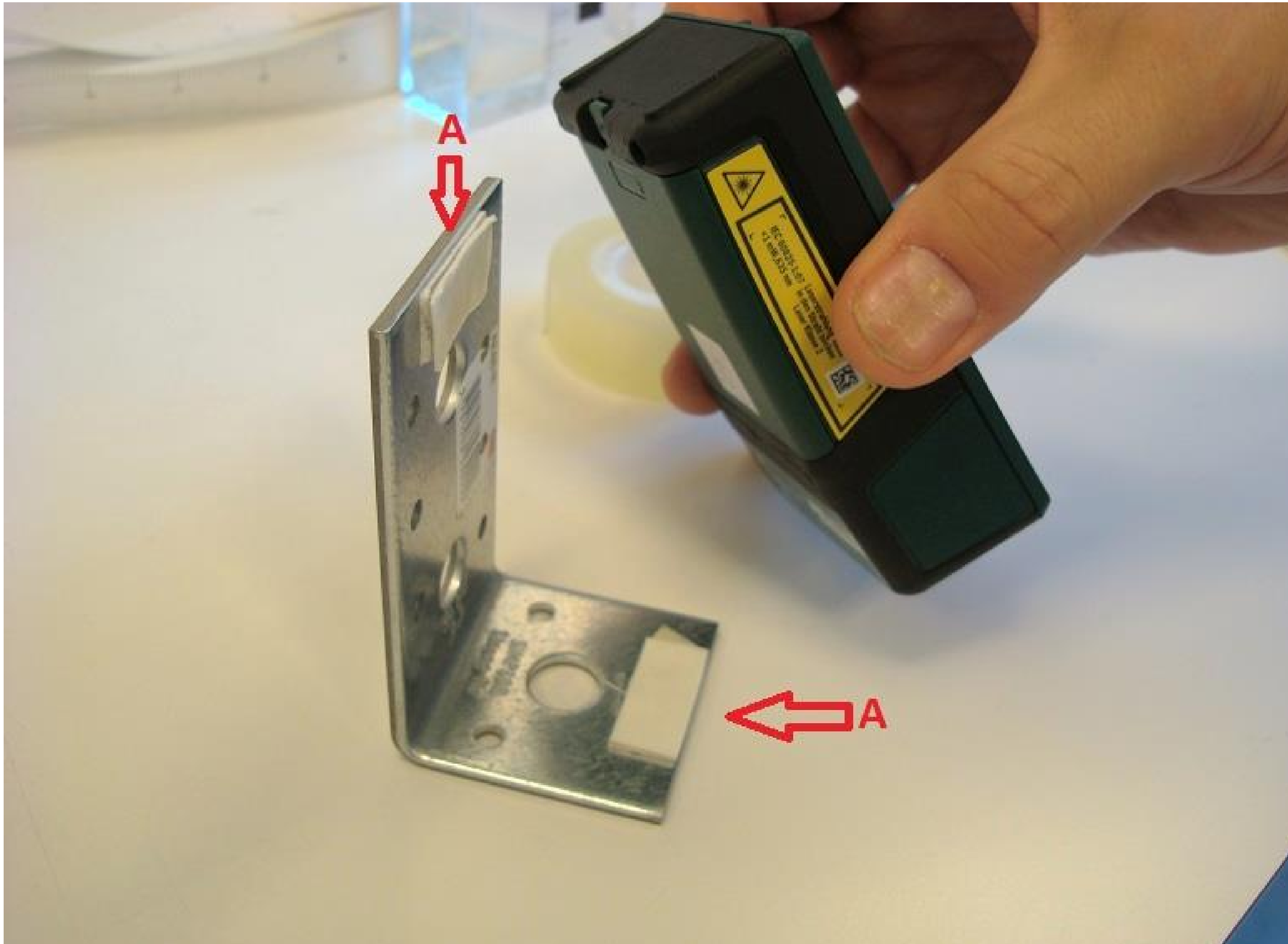
$$= 1 + \frac{1}{8}\left(\frac{\lambda}{an_{\text{co}}}\right)^2 \approx 1 + 2 \cdot 10^{-8}$$

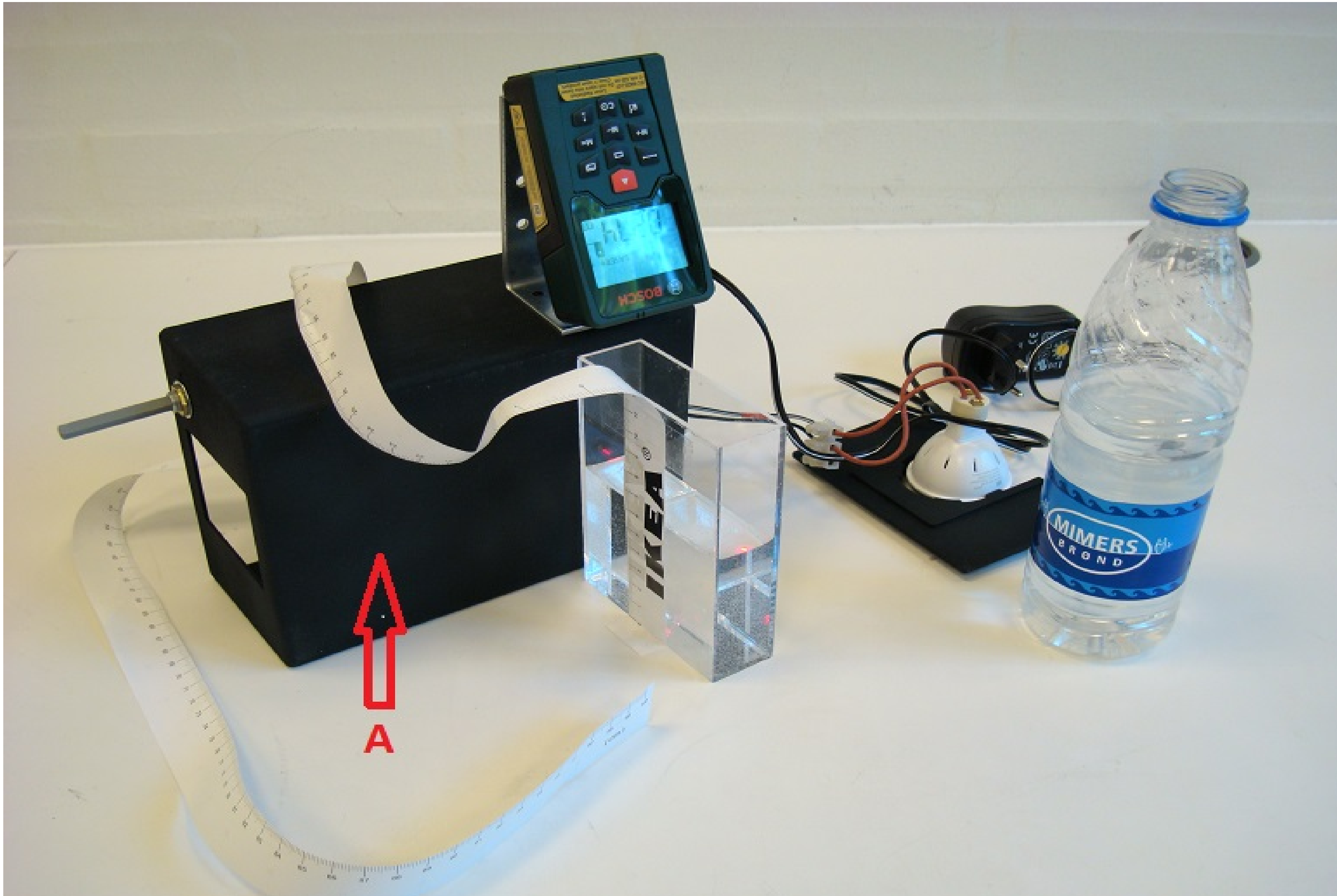
$a \approx 1\ \text{mm}$ is the core diameter

$\lambda = 635\ \text{nm}$

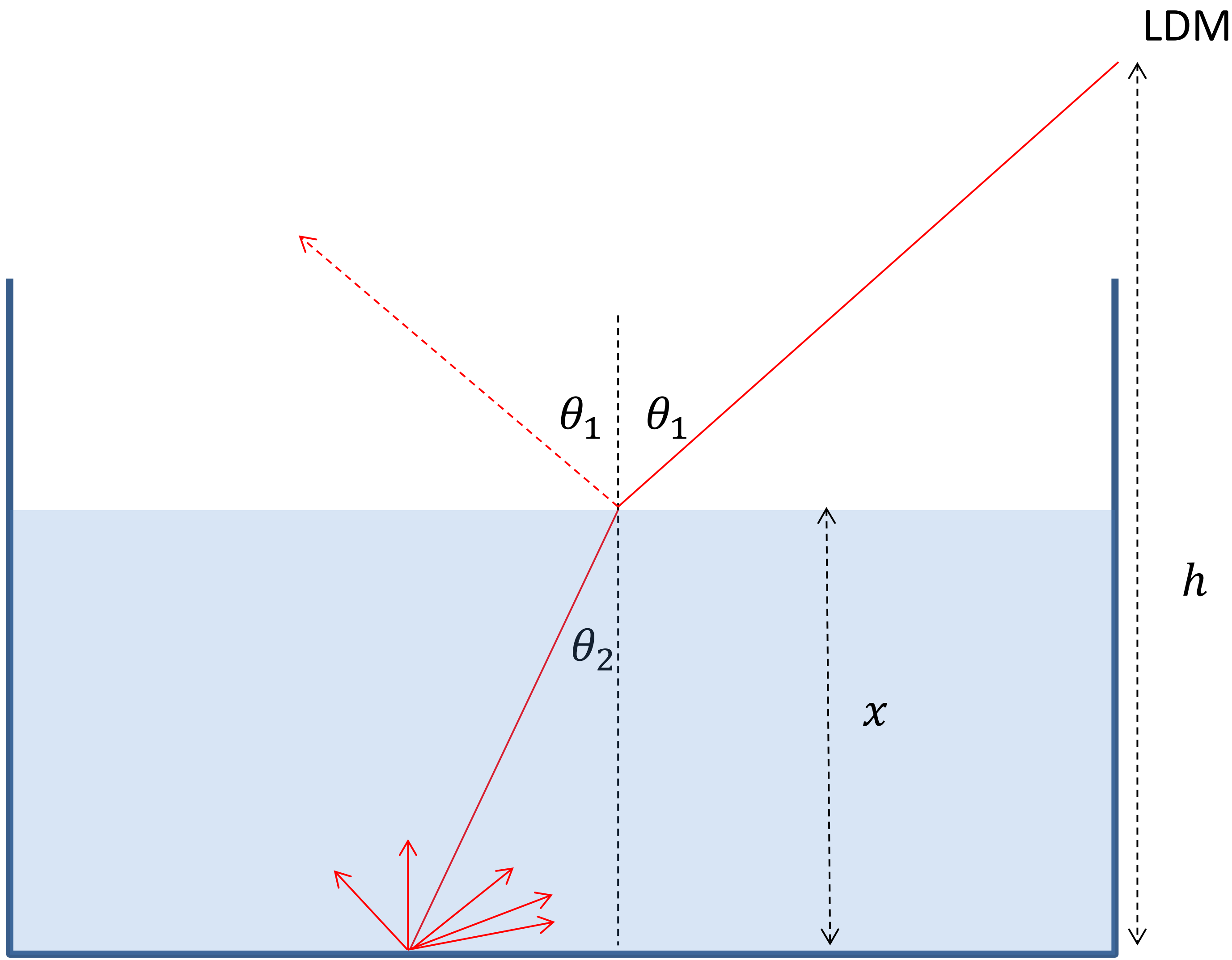
$n_{\text{co}} \approx 1.5$


A
B
C
D
IKEA
MIMERS
BOSCH

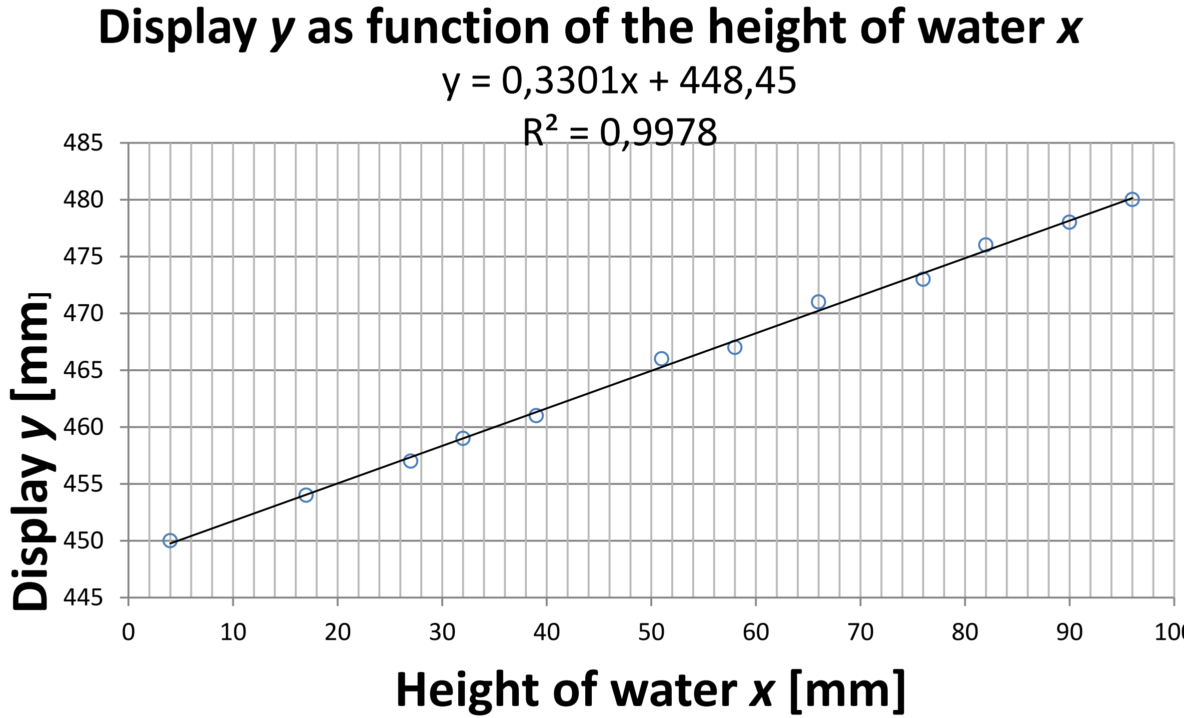

A
A



BOSCH
IKEA
MIMERS
BROND
A


LDM
θ_1
θ_1
θ_2
h
x

x	y
mm	mm
4	450
17	454
27	457
32	459
39	461
51	466
58	467
66	471
76	473
82	476
90	478
96	480



We show later that this must be an *increasing* linear function as long as the angle of incidence is less than the Brewster angle: $\theta_1 < 53.08°$

We want the student to explain the shape of the graph

The time it takes the light to reach the water surface is

$$t_1 = \frac{(h - x)/\cos\theta_1}{c}$$

From the water surface to the bottom the light uses the time

$$t_2 = \frac{x/\cos\theta_2}{v}$$

Total travel time forth and back

$$t = 2t_1 + 2t_2 = 2\frac{(h - x)/\cos\theta_1}{c} + 2\frac{x/\cos\theta_2}{v} = 2\frac{h - x}{c\cos\theta_1} + 2\frac{nx}{c\cos\theta_2}$$

Hence, the display will show (we simply write $n = n_{\mathrm{w}}$)

$$y = ½ct + k = \left(\frac{n}{\cos\theta_2} - \frac{1}{\cos\theta_1}\right)x + \frac{h}{\cos\theta_1} + k$$

This is a linear function of x.

Using a trigonometric identity and Snell's law,

$$\cos\theta_2 = \sqrt{1-\sin^2\theta_2} = \sqrt{1-\frac{\sin^2\theta_1}{n^2}}$$

we find the gradient of the linear graph to be

$$\alpha = \frac{n^2}{\sqrt{n^2-\sin^2\theta_1}} - \frac{1}{\cos\theta_1}$$

We want the students to find the refractive index of water using the graph only

To do so, the student must find the gradient α of the linear graph and solve the equation above with respect to n.
Introducing a practical parameter,

$$p = \alpha + \frac{1}{\cos\theta_1}$$

our equation can be rearranged

$$n^4 - p^2 n^2 + p^2 \sin^2\theta_1 = 0$$

and solved for n:

$$n_\mathrm{w} = \sqrt{\frac{p^2 \pm \sqrt{p^4 - 4p^2\sin^2\theta_1}}{2}} = \frac{\sqrt{2}}{2} p \sqrt{1 \pm \sqrt{1 - \left(\frac{2\sin\theta_1}{p}\right)^2}}$$

From our graph, we get $\alpha = 0{,}3301$.

From there we find $p = 1{,}37865$ and hence

$$n_{\mathrm{w}} = 1{,}34$$

omitting negative solutions and solutions less than 1.

The official value of n_{w} for pure water at normal conditions is $n_{\mathrm{w}} = 1{,}33$ for the laser wavelength $\lambda = 635\ \mathrm{nm}$.

What to worry about

- False spots because of beam splitting (multiple returned signals)
- Hitting the vertical edge of the vessel (2 ways)

How does the gradient

$$\alpha = \frac{n^2}{\sqrt{n^2 - \sin^2\theta_1}} - \frac{1}{\cos\theta_1}$$

depend on the angle θ_1? $\alpha = 0 \Leftrightarrow \tan(\theta_1) = n$

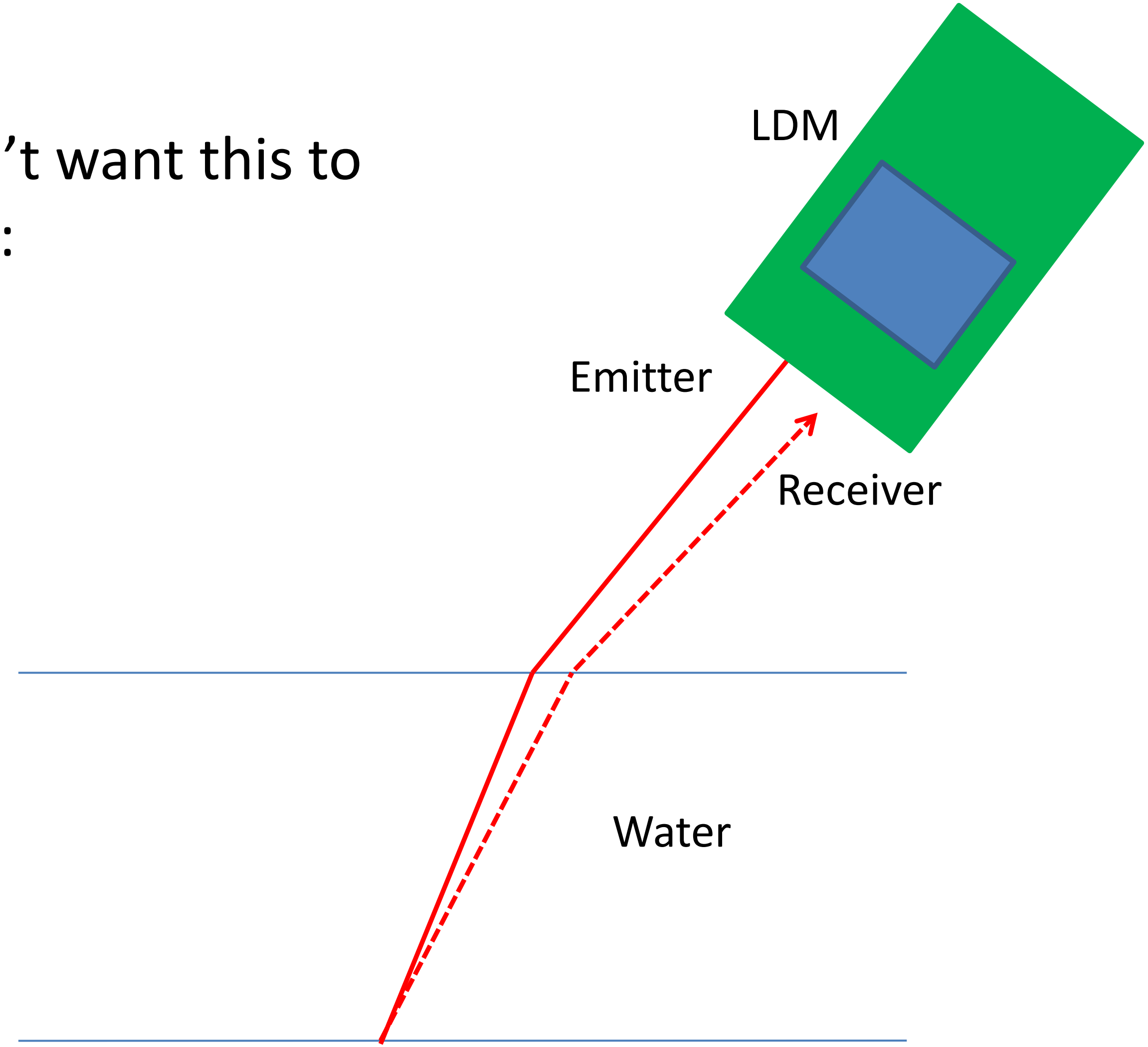
There is a sign change at the Brewster angle $\approx 53°$

The gradient α as a function of the angle of incidence θ_1

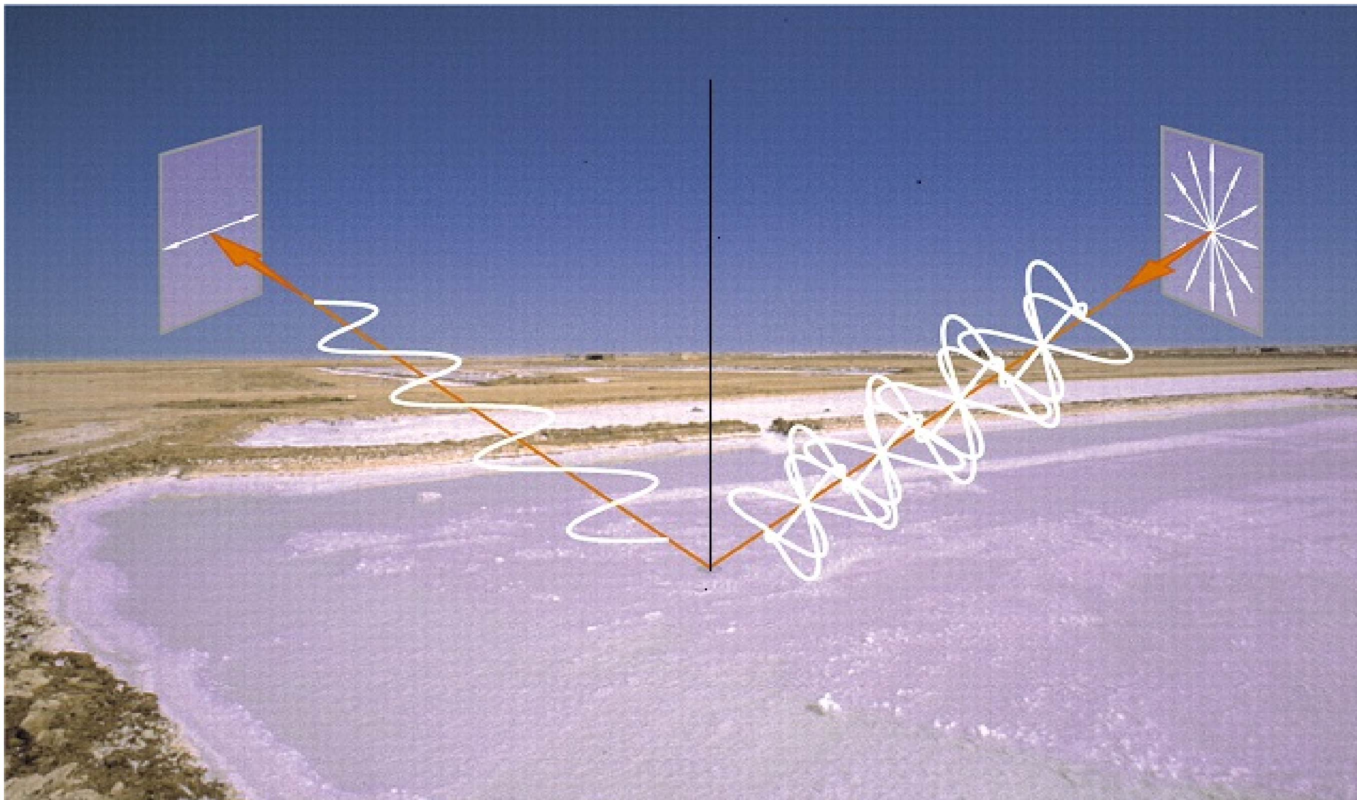
Don't worry about

- Geometry
- Polarization
- Brewster angle: $\tan(\theta_1) = n_\mathrm{w},\ \theta_1 \approx 53{,}08°$
- The transparent bottom

We don't want this to happen:



Polarization



Reflectance, transmittance

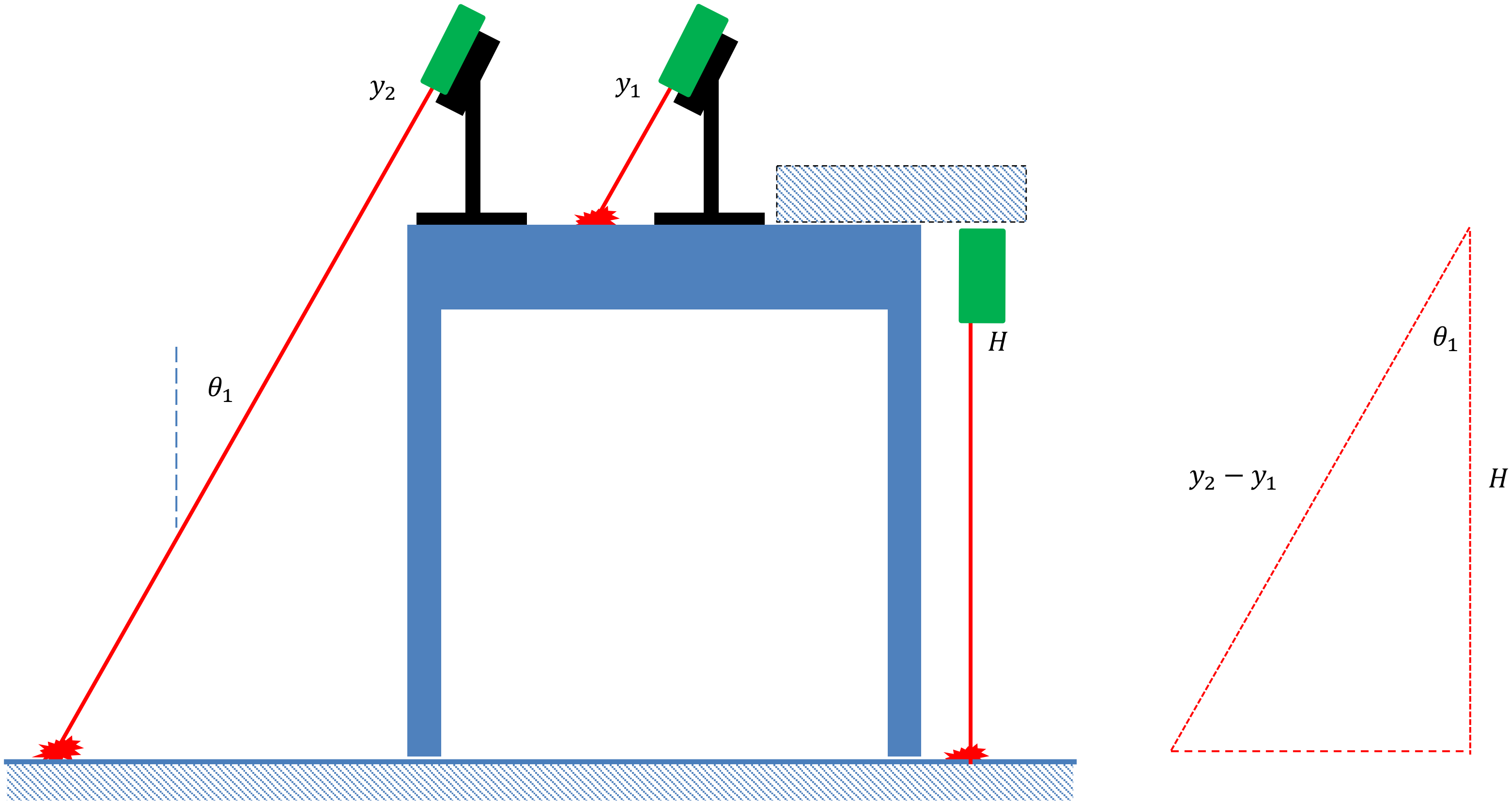
How to find the angle of incidence?

*We want it less than the Brewster angle ($\alpha > 0$)

*We want it greater than zero (reflections)

*An optimal angle is between $16°$ and $19.5°$

A taylor must use the same tape measure for measuring and cutting



y_2
y_1
θ_1
H
θ_1
$y_2 - y_1$
H

Syllabus

Appendix to the Statutes of the International Physics Olympiads

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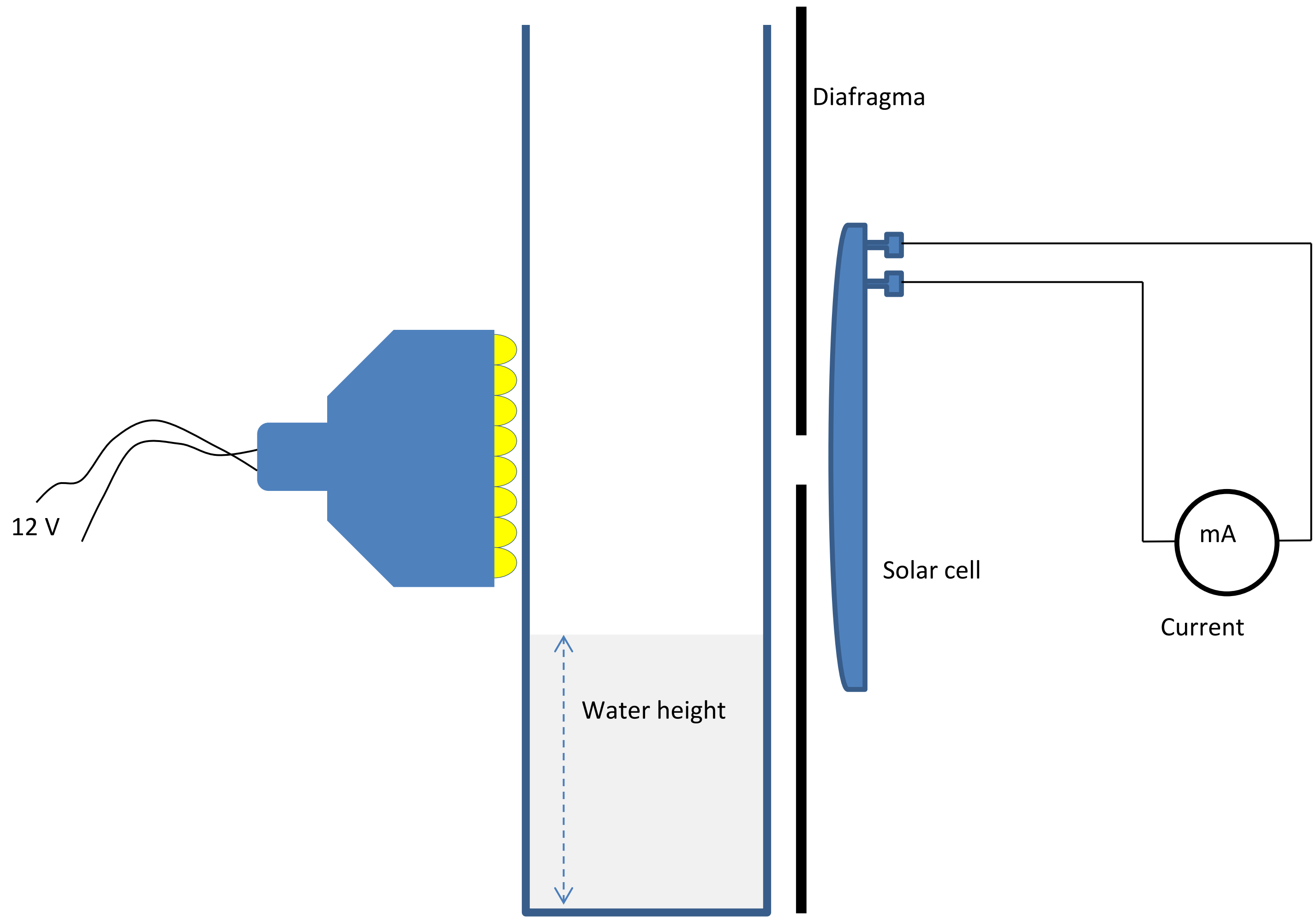
General

5. Oscillations and waves

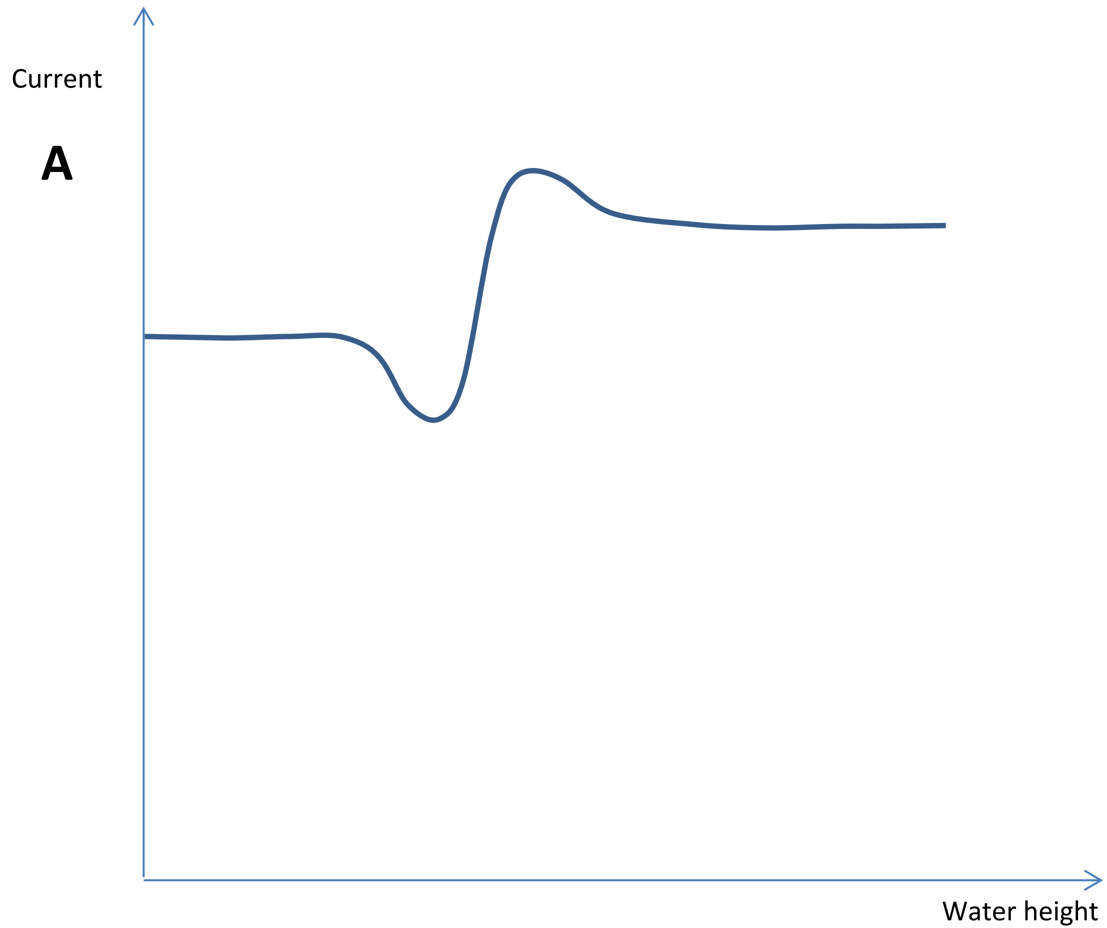
a) Harmonic oscillations, equation of harmonic oscillation	Solution of the equation for harmonic motion, attenuation and resonance -qualitatively
b) Harmonic waves, propagation of waves, transverse and longitudinal waves, linear polarization, the classical Doppler effect, sound waves	Displacement in a progressive wave and understanding of graphical representation of the wave, measurements of velocity of sound and light, Doppler effect in one dimension only, propagation of waves in homogeneous and isotropic media, reflection and refraction, Fermat's principle
c) Superposition of harmonic waves, coherent waves, interference, beats, standing waves	Realization that intensity of wave is proportional to the square of its amplitude. Fourier analysis is not required but candidates should have some understanding that complex waves can be made from addition of simple sinusoidal waves of different frequencies. Interference due to thin films and other simple systems (final formulae are not required), superposition of waves from secondary sources (diffraction)

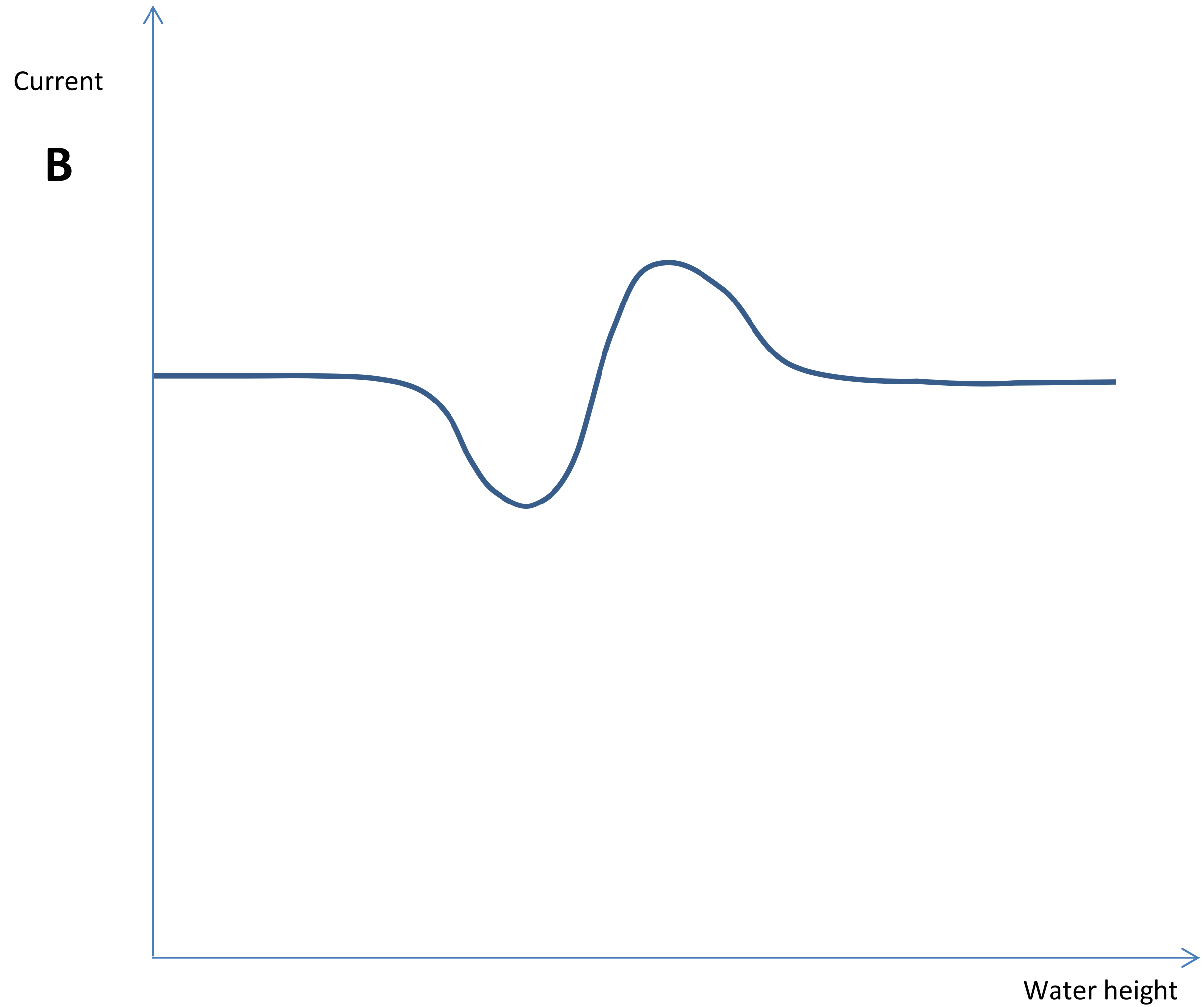
7. Current and Magnetic Field

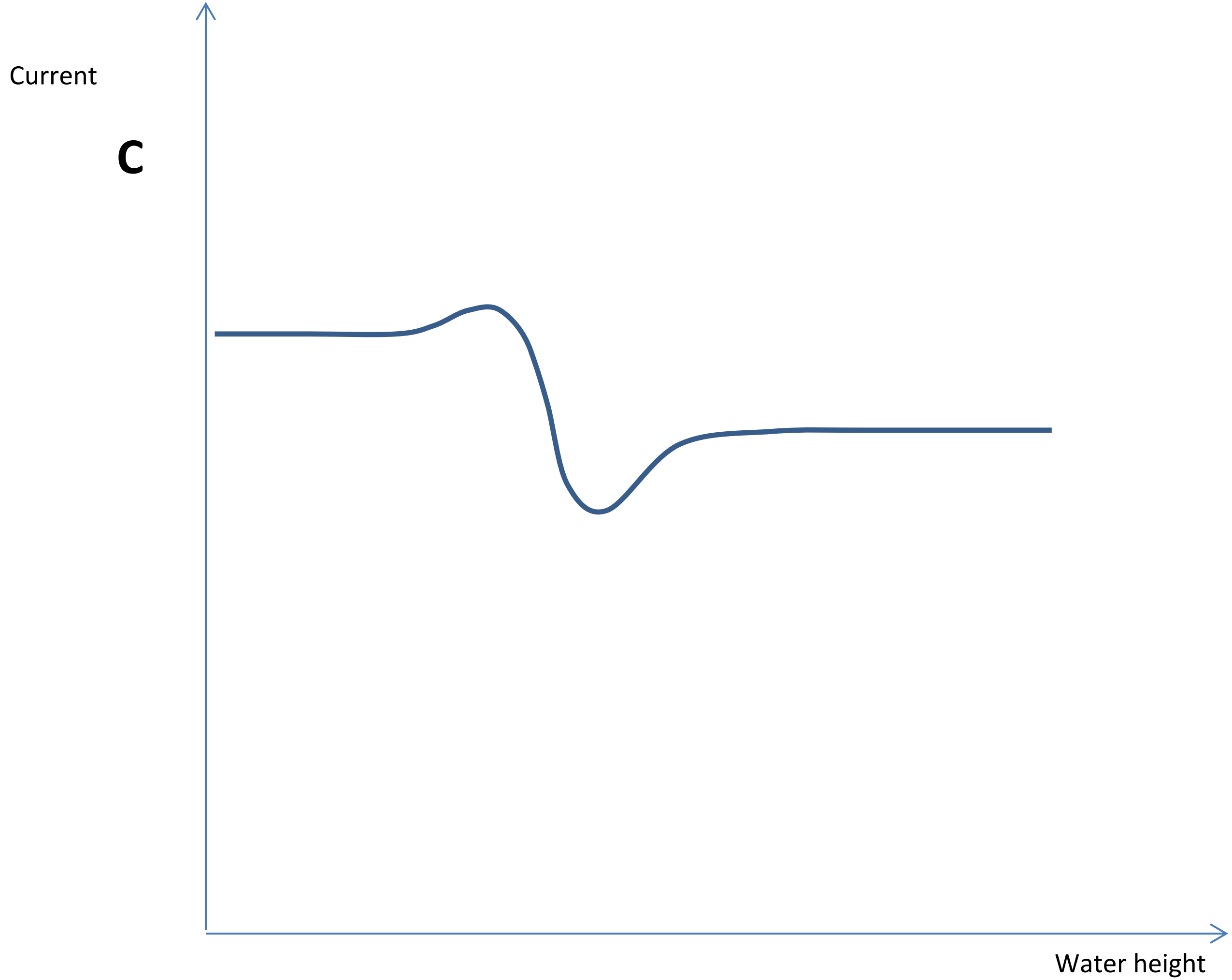
a) Current, resistance, internal resistance of source, Ohm's law, Kirchhoff's laws, work and power of direct and alternating currents, Joule's law	Simple cases of circuits containing non-ohmic devices with known V-I characteristics
b) Magnetic field (B) of a current, current in a magnetic field, Lorentz force	Particles in a magnetic field, simple applications like cyclotron, magnetic dipole moment
c) Ampere's law	Magnetic field of simple symmetric systems like straight wire, circular loop and long solenoid
d) Law of electromagnetic induction, magnetic flux, Lenz's law, self-induction, inductance, permeability, energy density of magnetic field	
e) Alternating current, resistors, inductors and capacitors in AC-circuits, voltage and current (parallel and series) resonances	Simple AC-circuits, time constants, final formulae for parameters of concrete resonance circuits are not required

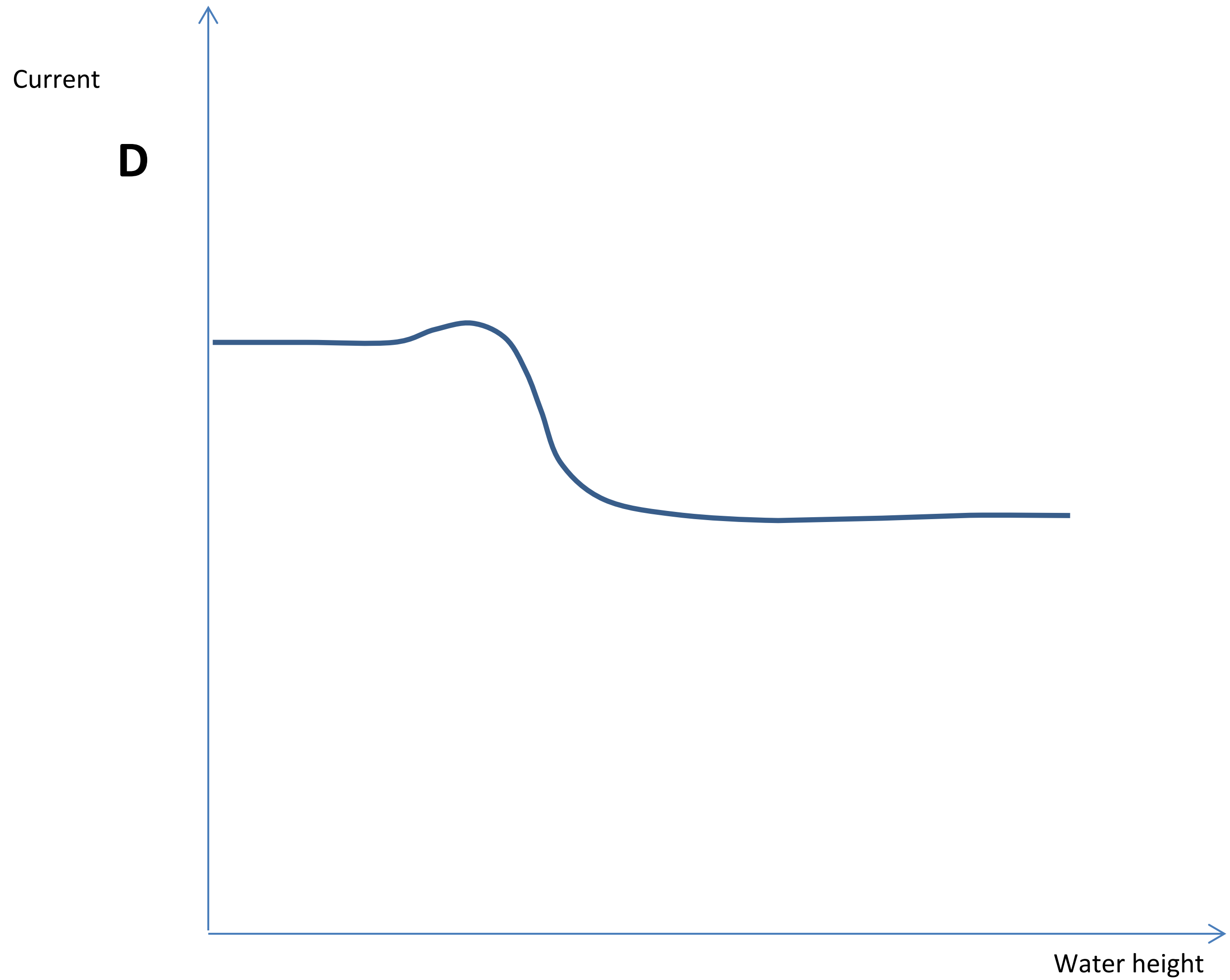

Diafragma
12 V
Solar cell
mA
Current
Water height

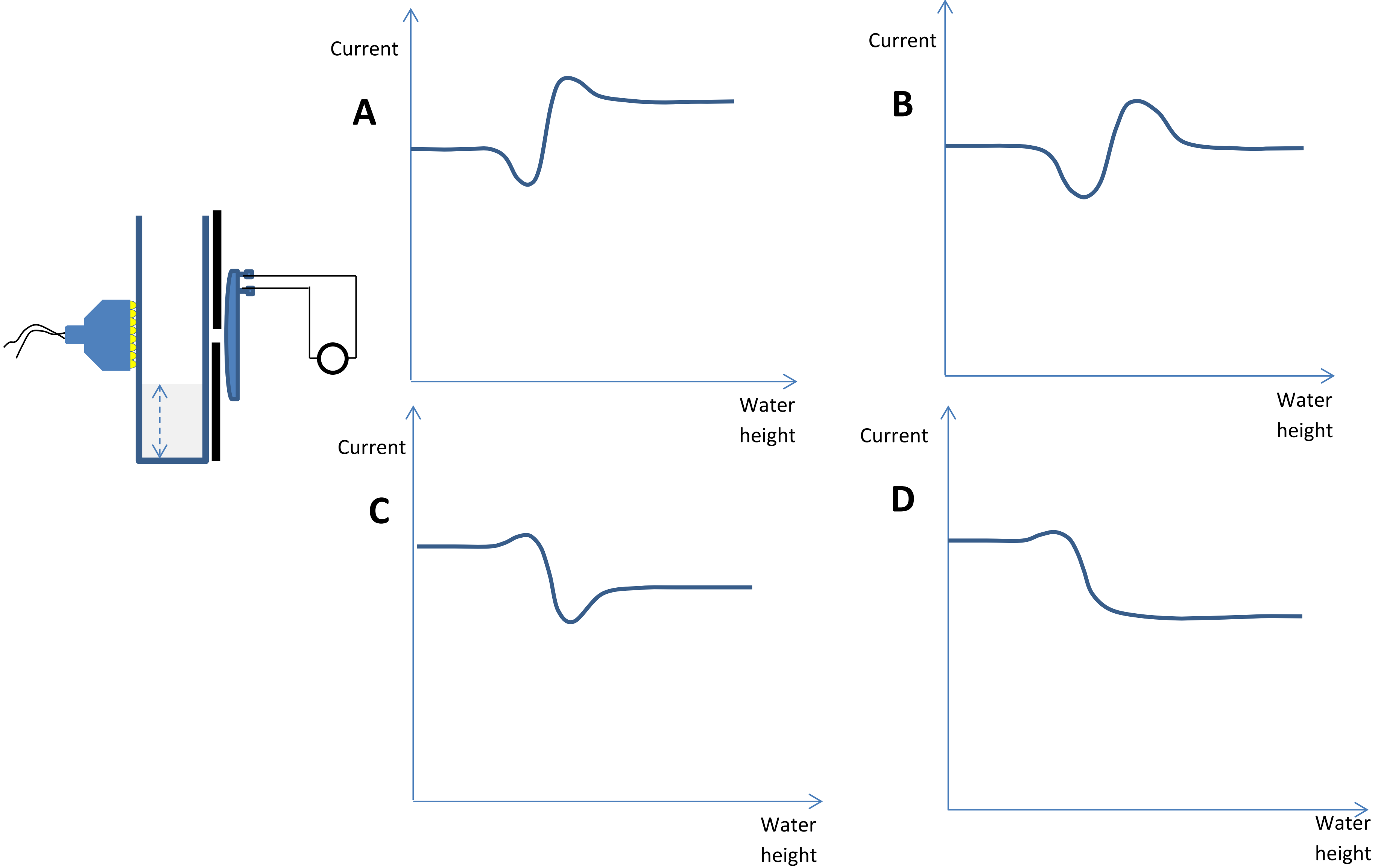
Guess which of the following four graphs shows the light intensity as function if the height of the water in the vessel


Current
A
Water height


Current
B
Water height

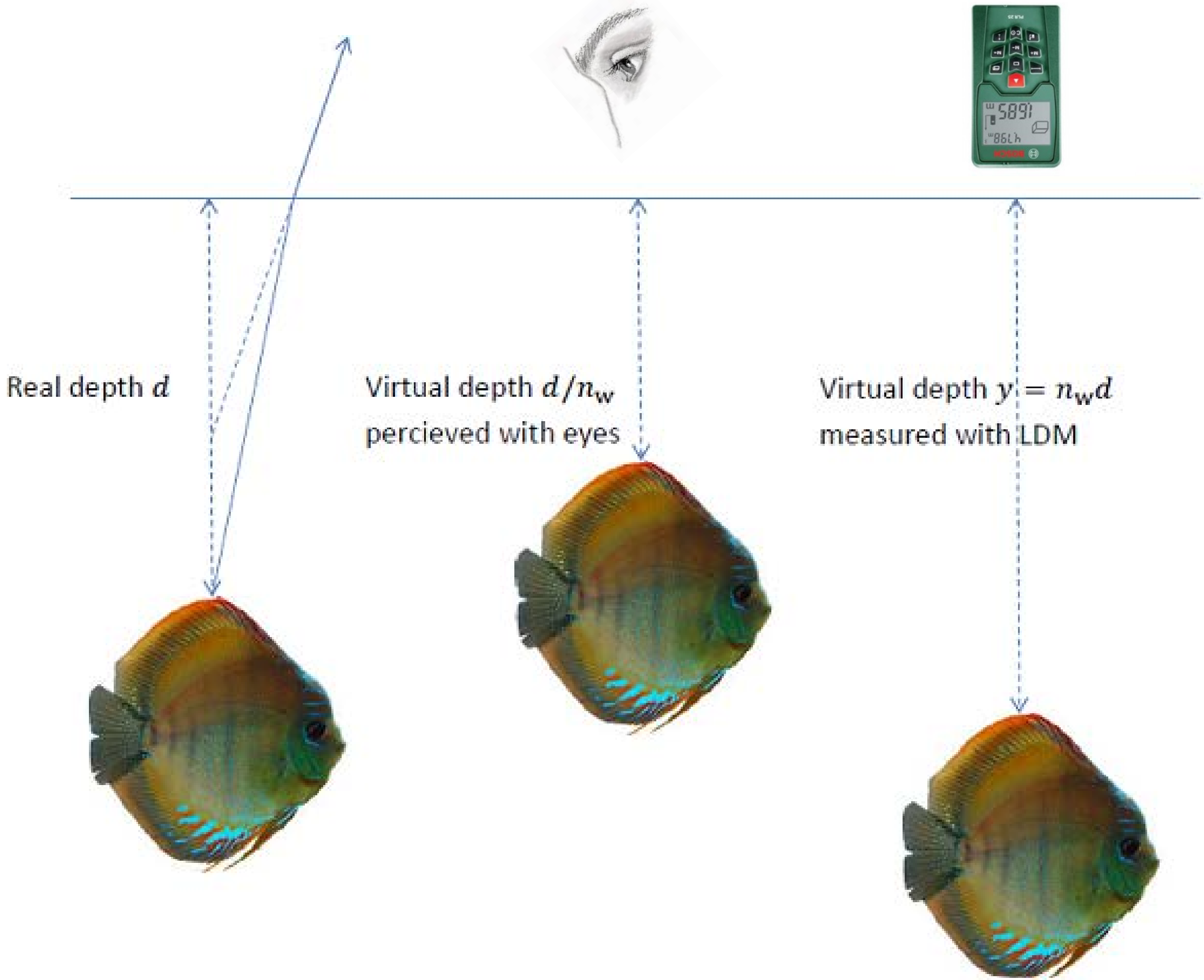

Current
C
Water height


Current
D
Water height

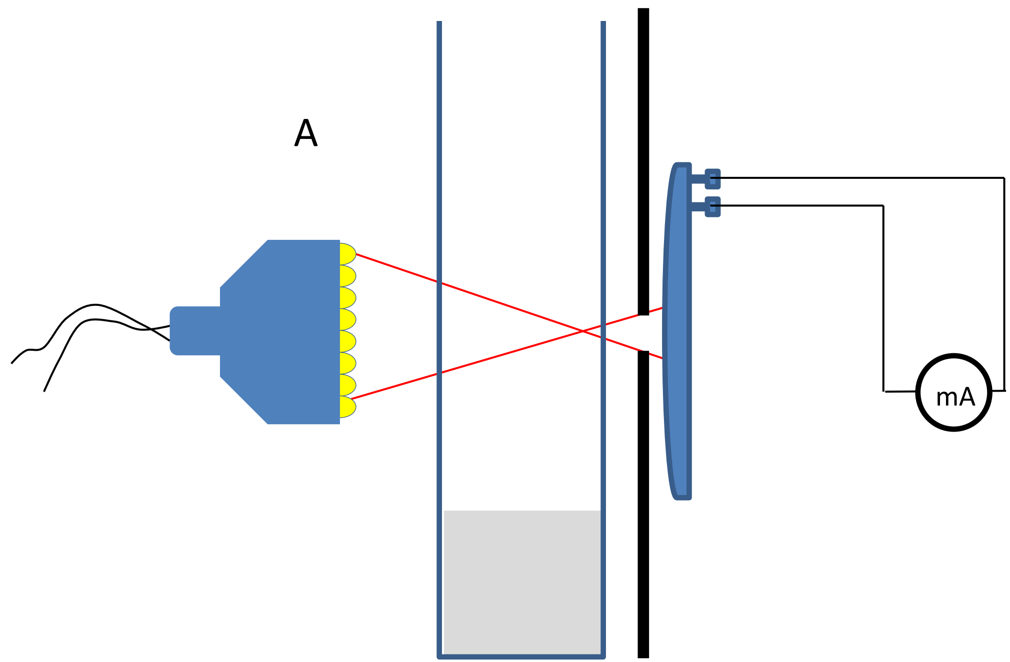

A
Current
Water height
B
Current
Water height
C
Current
Water height
D
Current
Water height

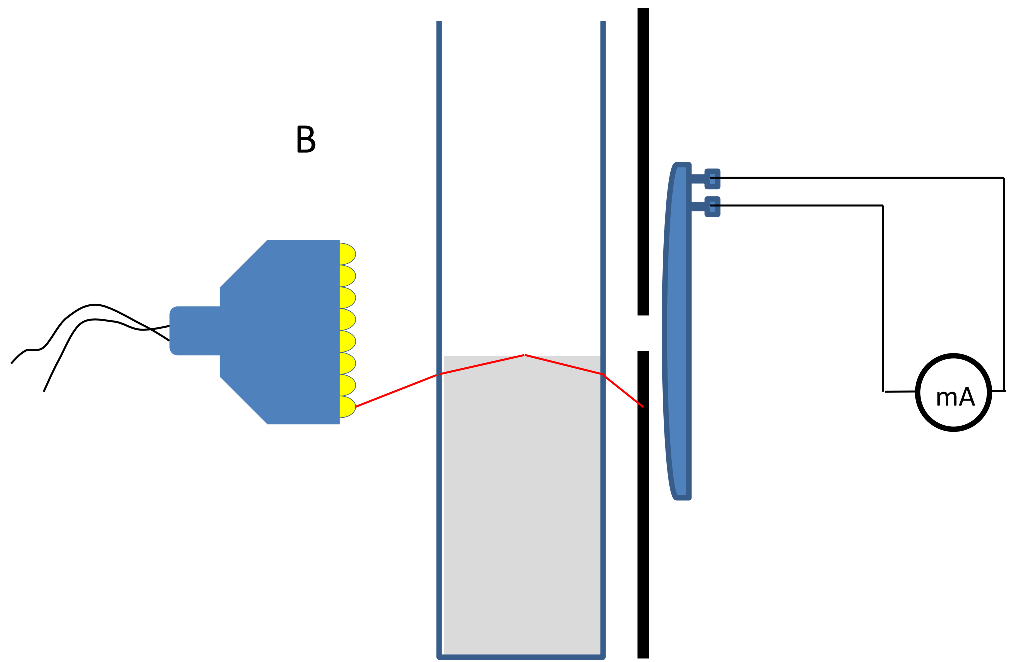
How do we find the depth of a fish?

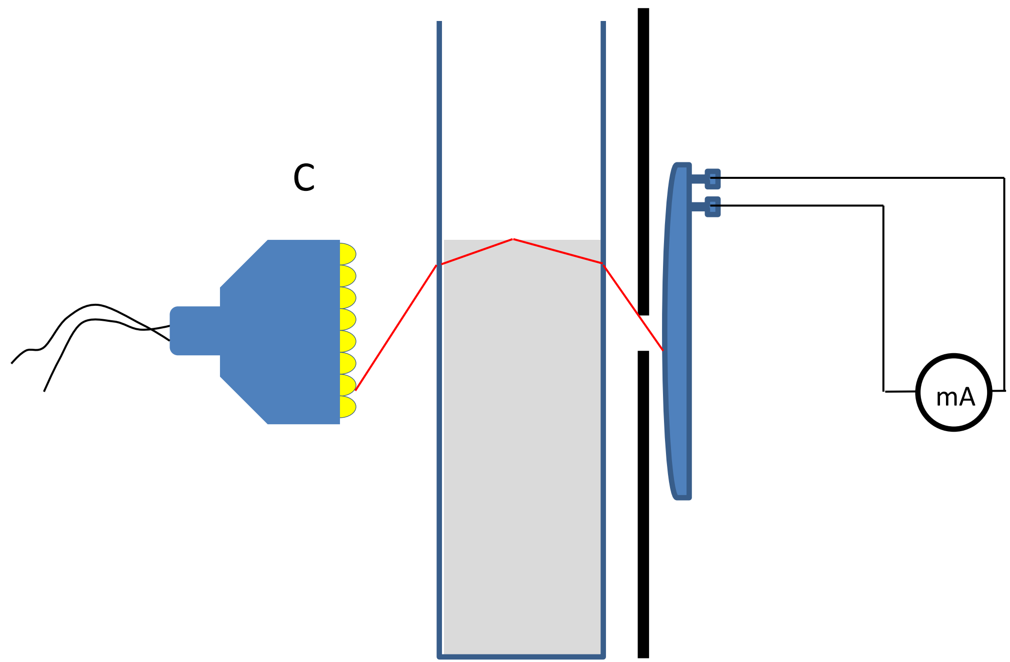
No problem watching from the side

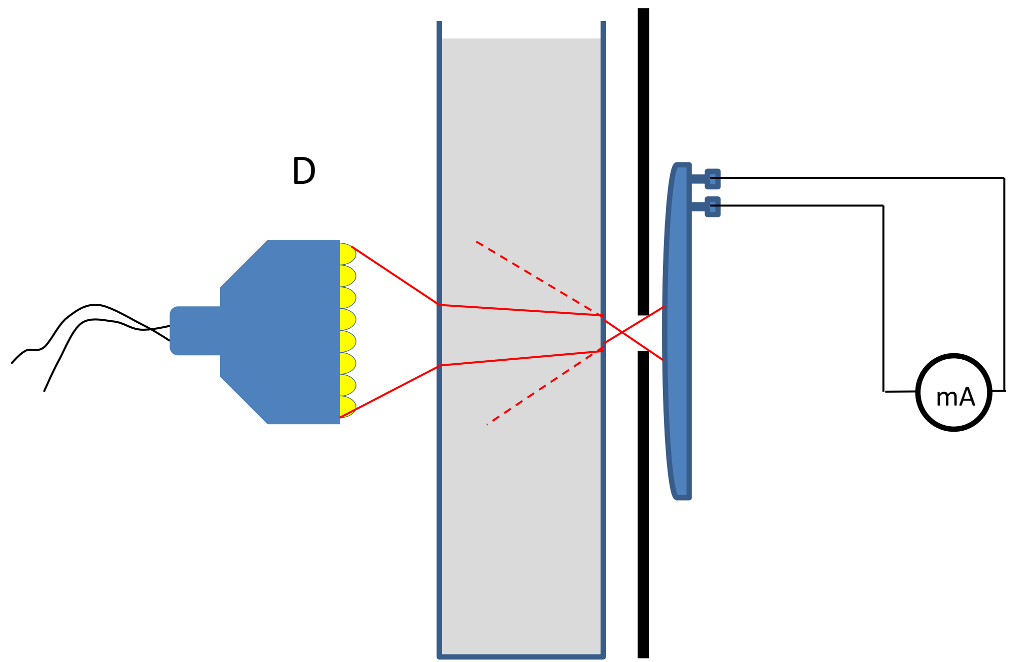


Real depth d
Virtual depth d/n_w
percieved with eyes
Virtual depth $y = n_\mathrm{w} d$
measured with LDM


A
mA


B
mA


C
mA


D
mA