Maxwellovy a Hertzovy Elektromagnetické vlny

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Z komiksu Csenge Kindli
(webgram.co/csenge.kindli)

Obsah

- Trocha teorie
  (na co vlastně přišel J. C. Maxwell)

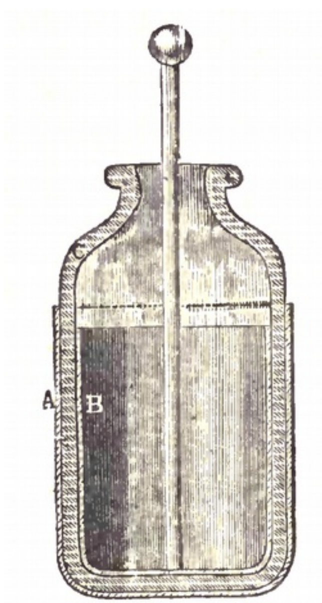
- První pokusy s vlnami
  (za ně může H. Hertz)

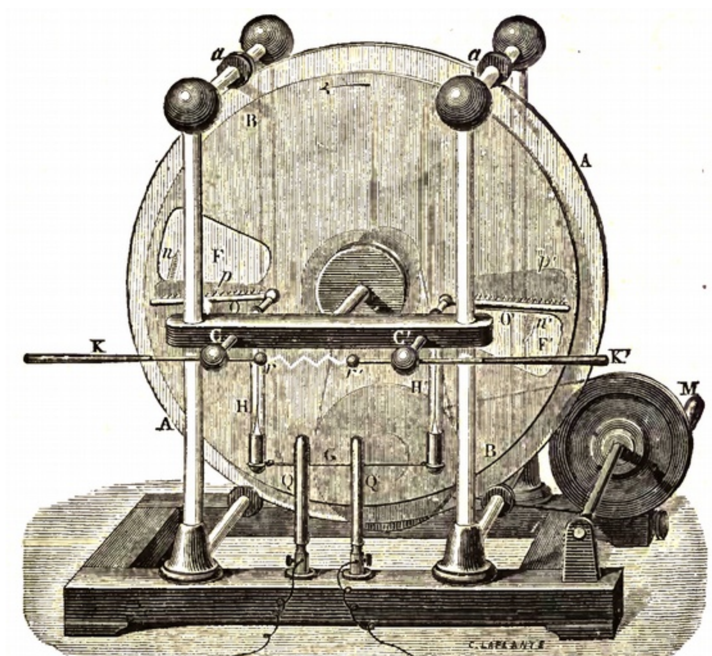
- Jak vyrobit EM vlny
  (na Zemi a ve vesmíru)

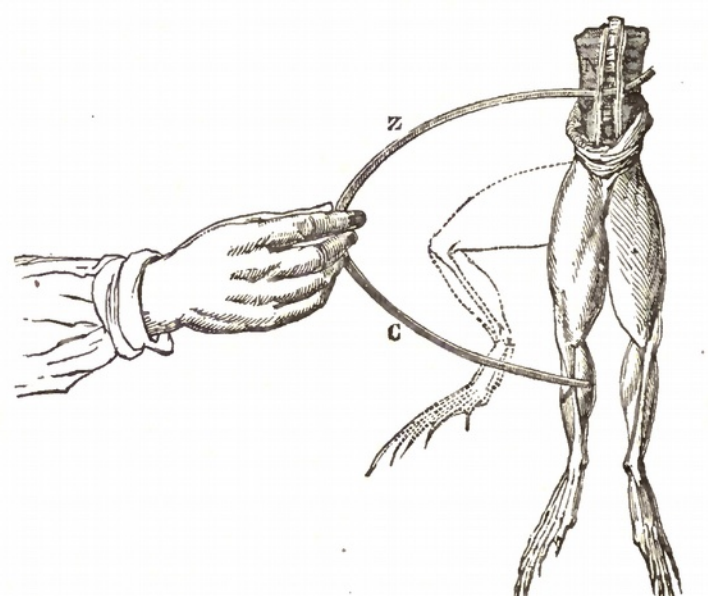
- Jak je zachytit
  (o tom se ale zmíním jen mezi řádky)

Elektrické a magnetické pole před objevem elektromagnetické indukce

- Náboje způsobují elektrické jevy (pole)
- Proudy způsobují magnetické jevy (pole)
- Nějak navzájem souvisí (Oersted)
- Mnoho zdrojů → superpozice (polí)



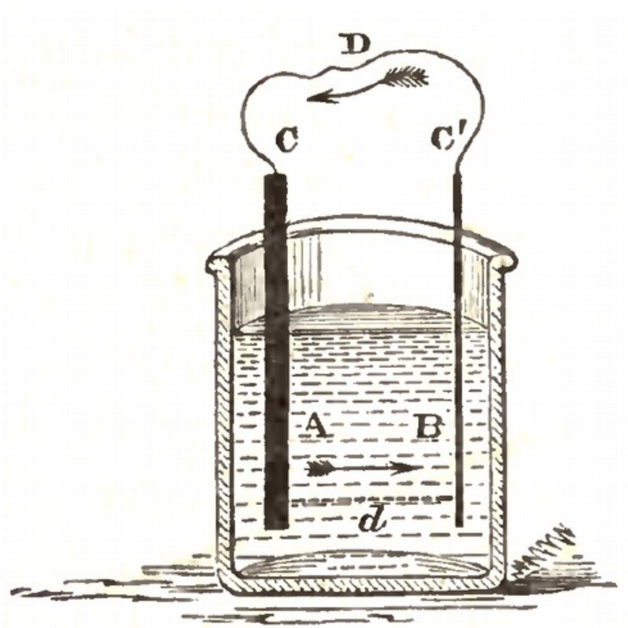


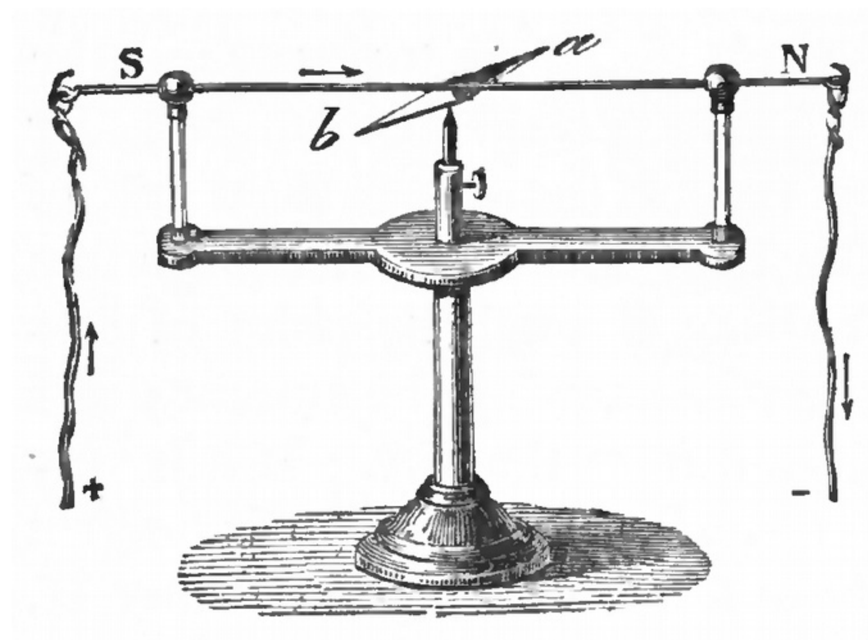


Elektrické a magnetické pole před objevem elektromagnetické indukce

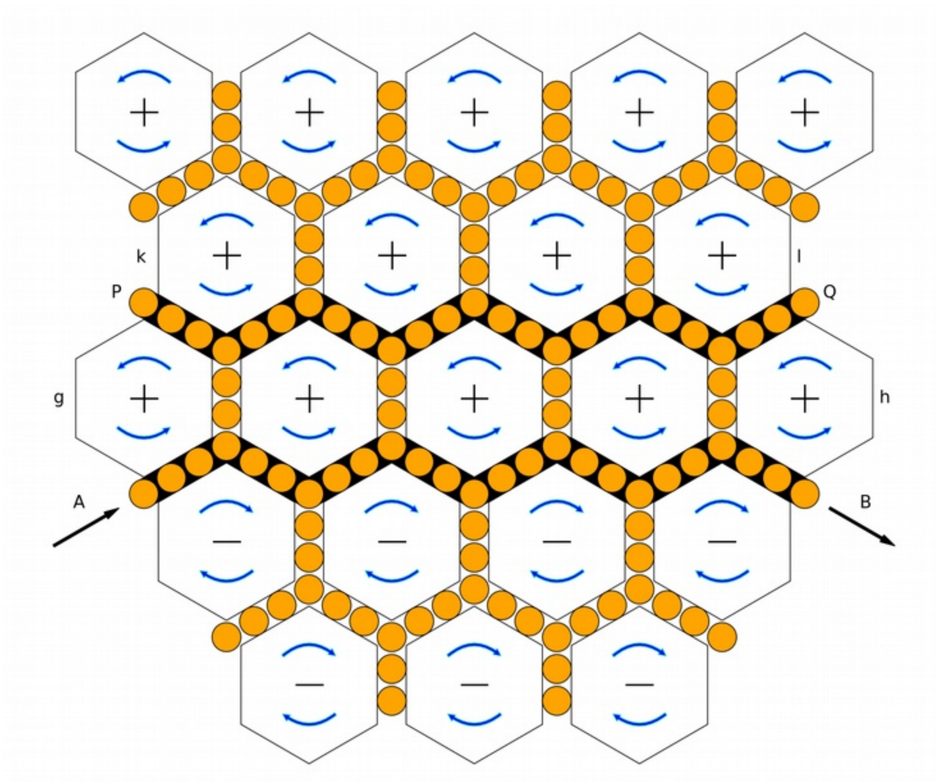
- Experimenty (… , *Cavendish*, Coulomb, Ampere, Faraday)
- Matematický popis (…, Laplace, Gauss, Ampere, …)
- pod dojmem úspěchu Newtonovké mechaniky se hledá správná Teorie

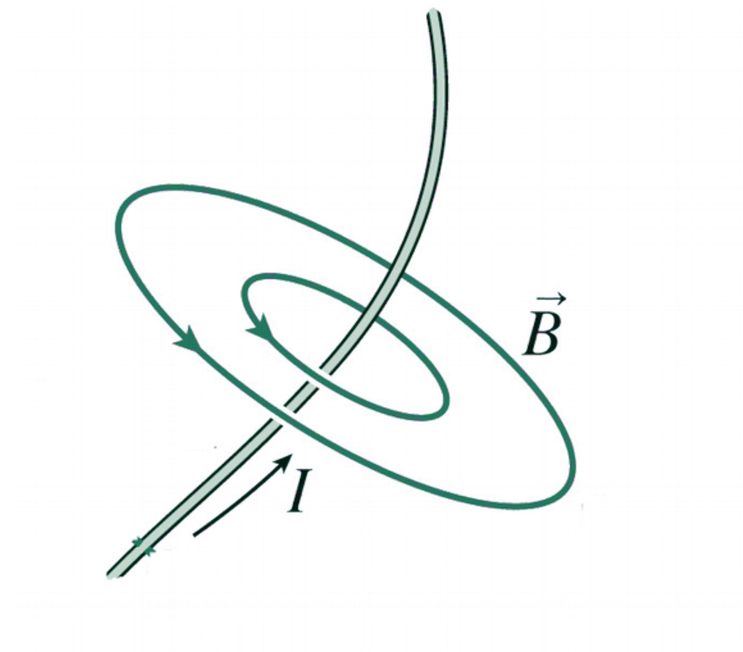
(varování: moderní pojmy dále používané tou dobou teprve vznikaly)





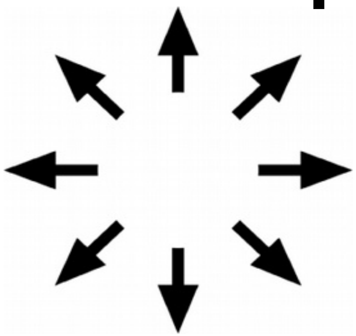
Maxwellův mechanický model



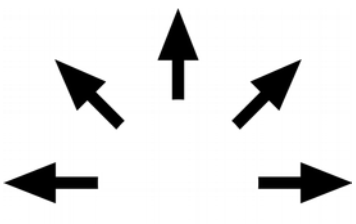


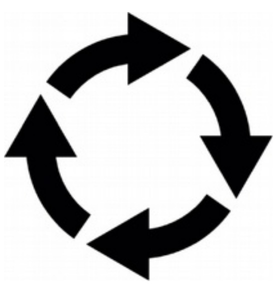
http://sites.google.com/site/perennialphysics/maxwel
l

Tok a cirkulace vektorů



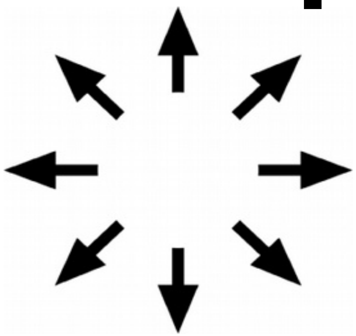
Tok vektorového pole
- počítá se přes **plochu**
- plocha **může** obklopovat nějaký objem
- důležitá jen složka vektorů **kolmá k ploše**
- součin plochy a průměrné kolmé složky

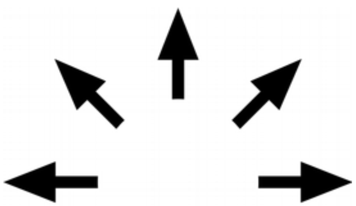


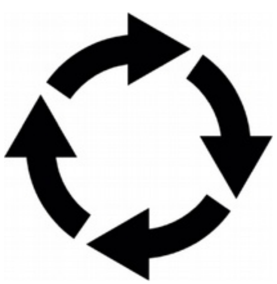


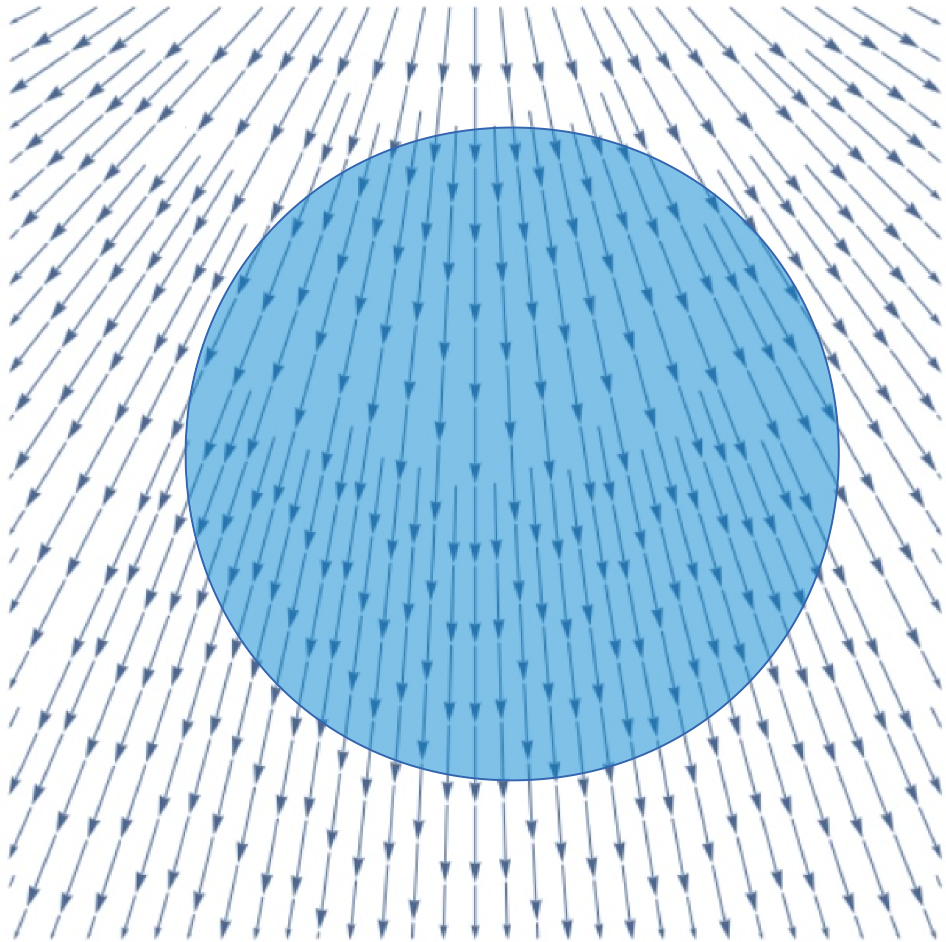
Cirkulace vektorového pole
- počítá se podél křivky
- důležitá je jen složka vektorů **podél křivky**
- součin délky a průměrné podélné složky

Tok a cirkulace vektorů









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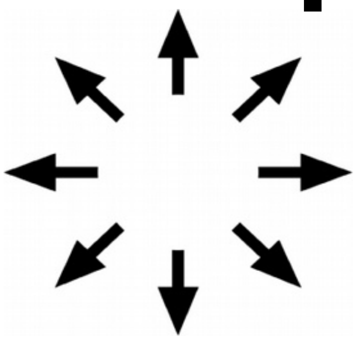

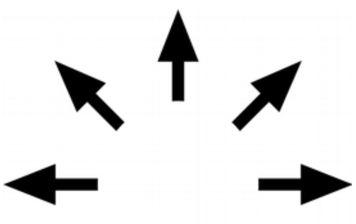

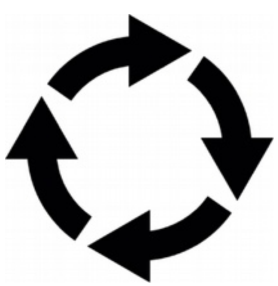

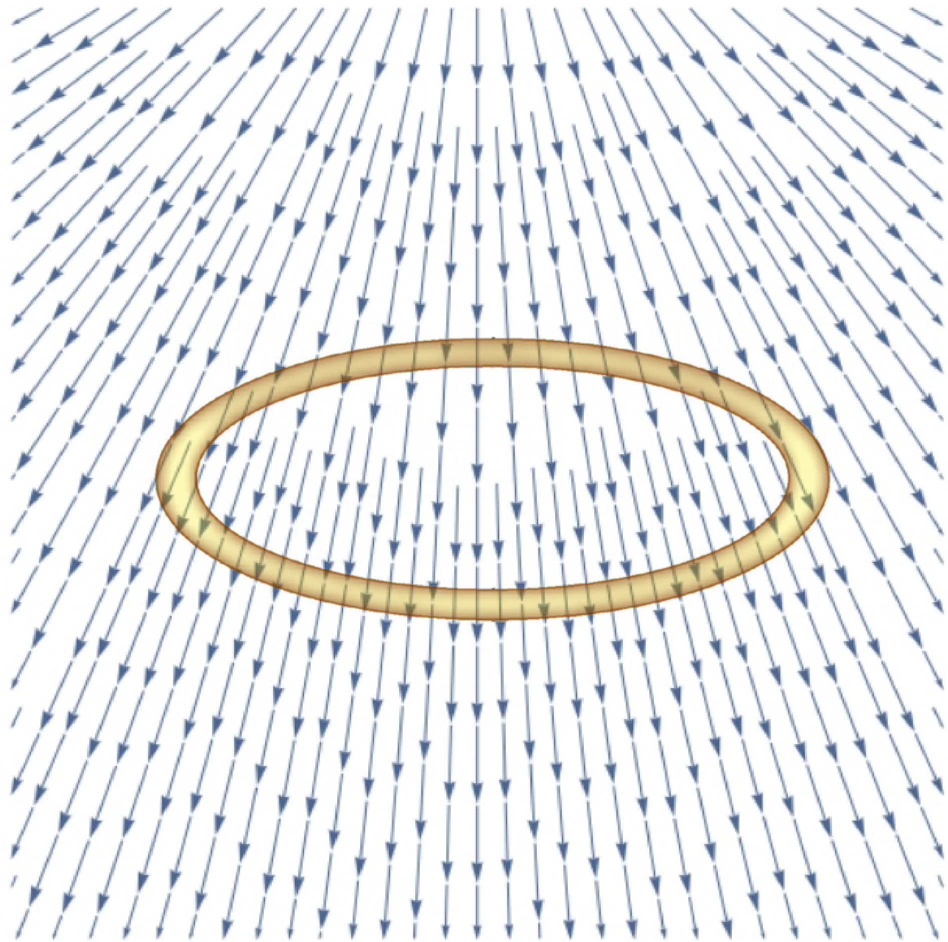

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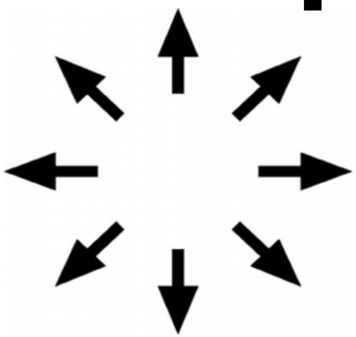
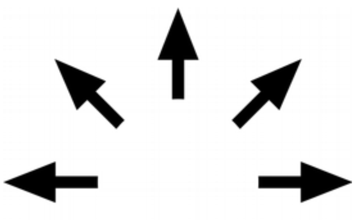
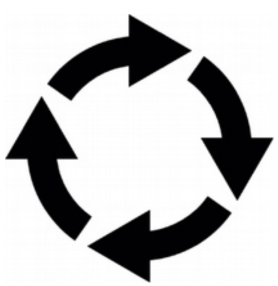
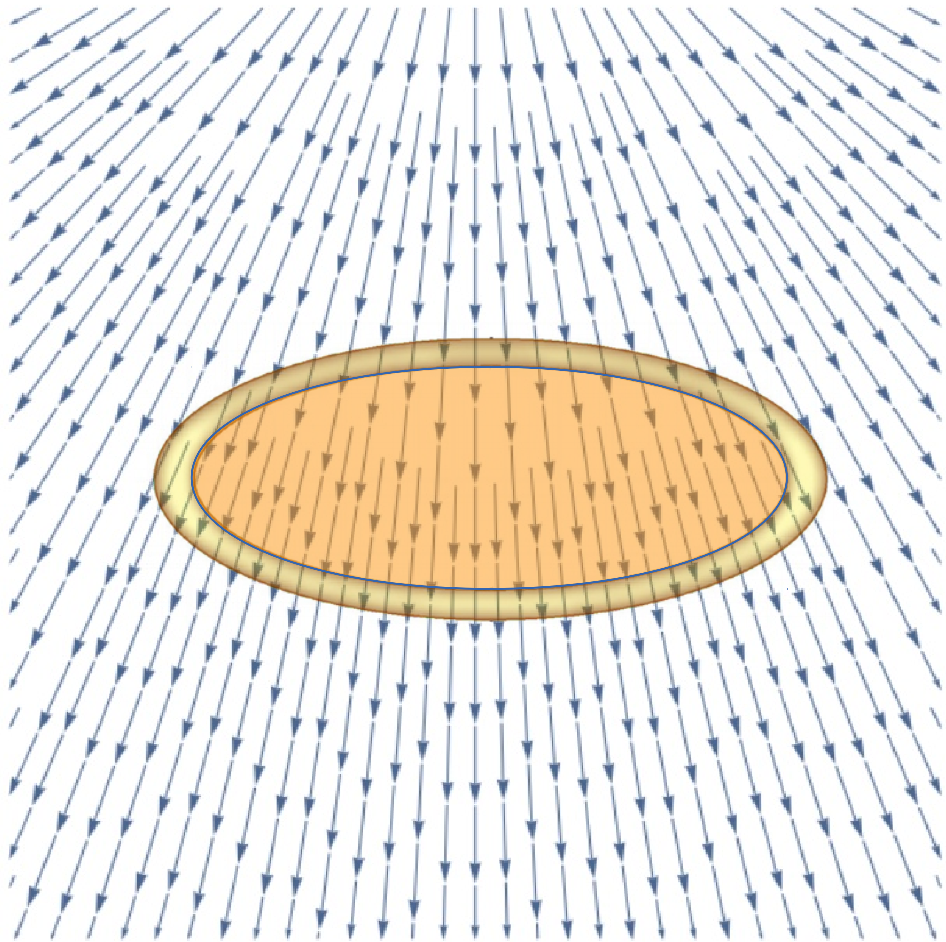
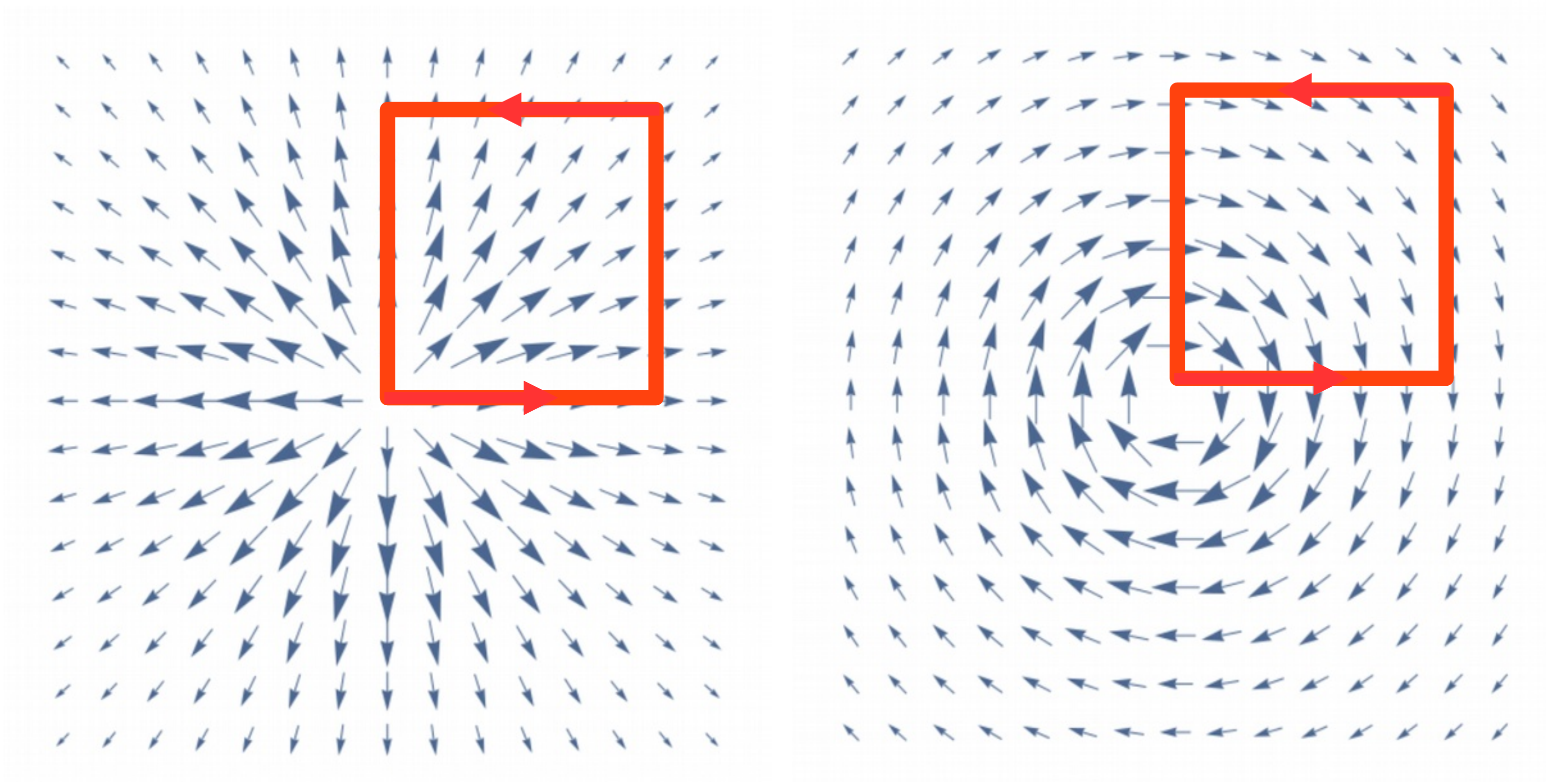


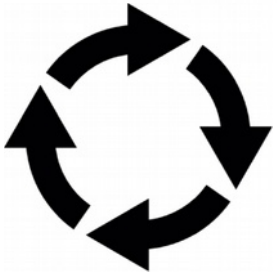






Tok a **cirkulace** vektorů



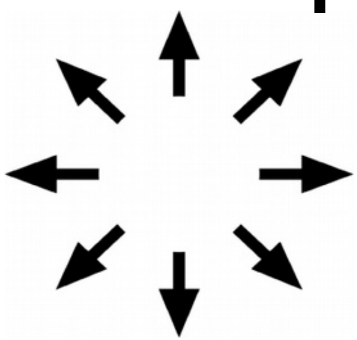


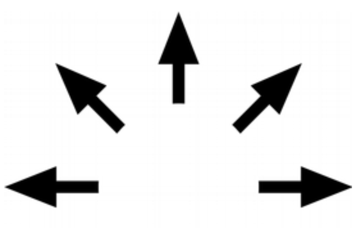
Cirkulace – aneb chodíme ve větru

vlevo – co na začátku ušetříme, na konci zase vydáme

vpravo – celou dobu půjdeme proti větru

Tok a cirkulace vektorů





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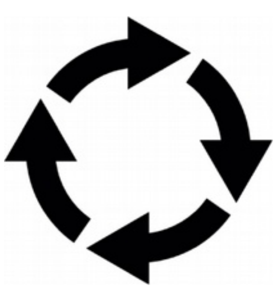

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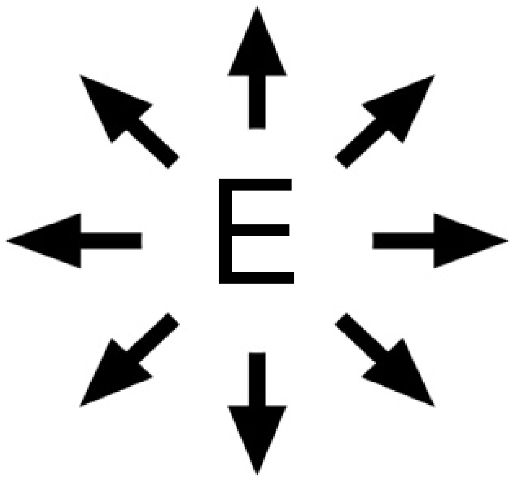
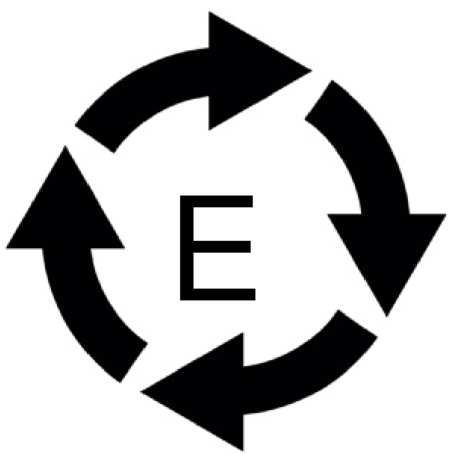
Rovnice elektrostatického pole



= náboj



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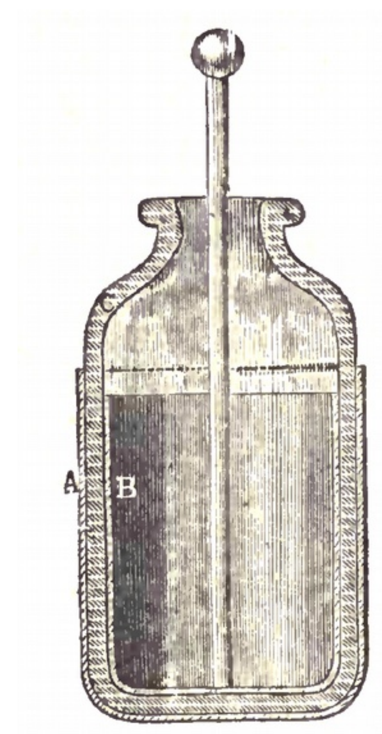
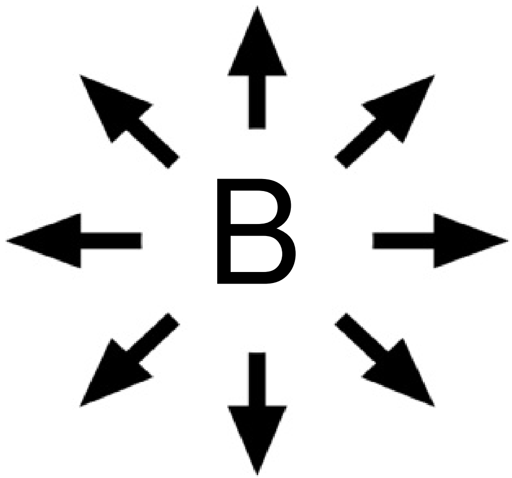


Rovnice magnetického pole



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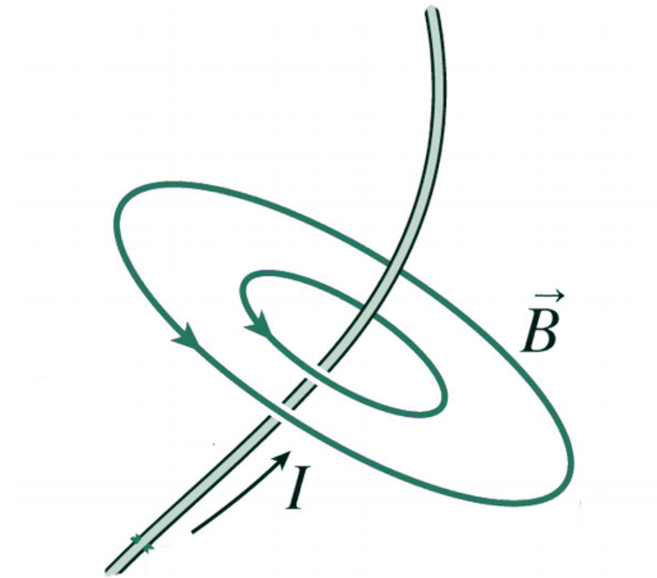
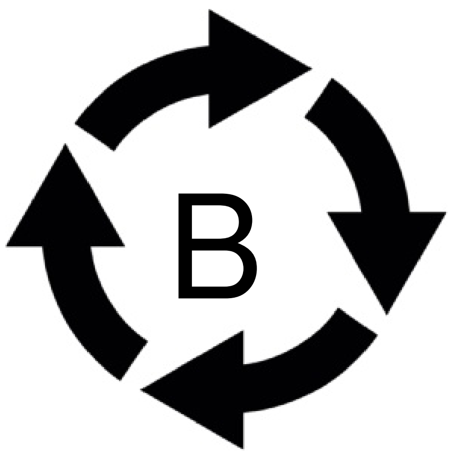
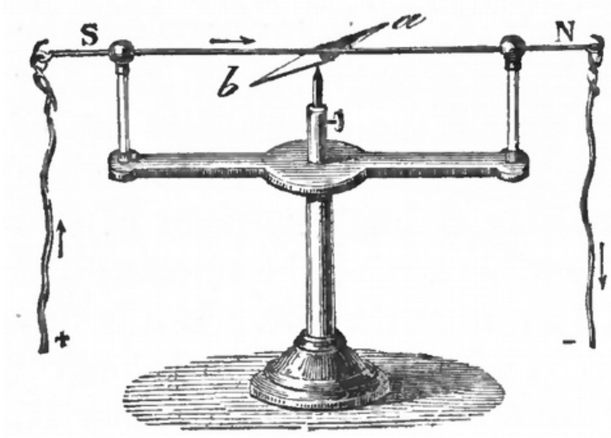




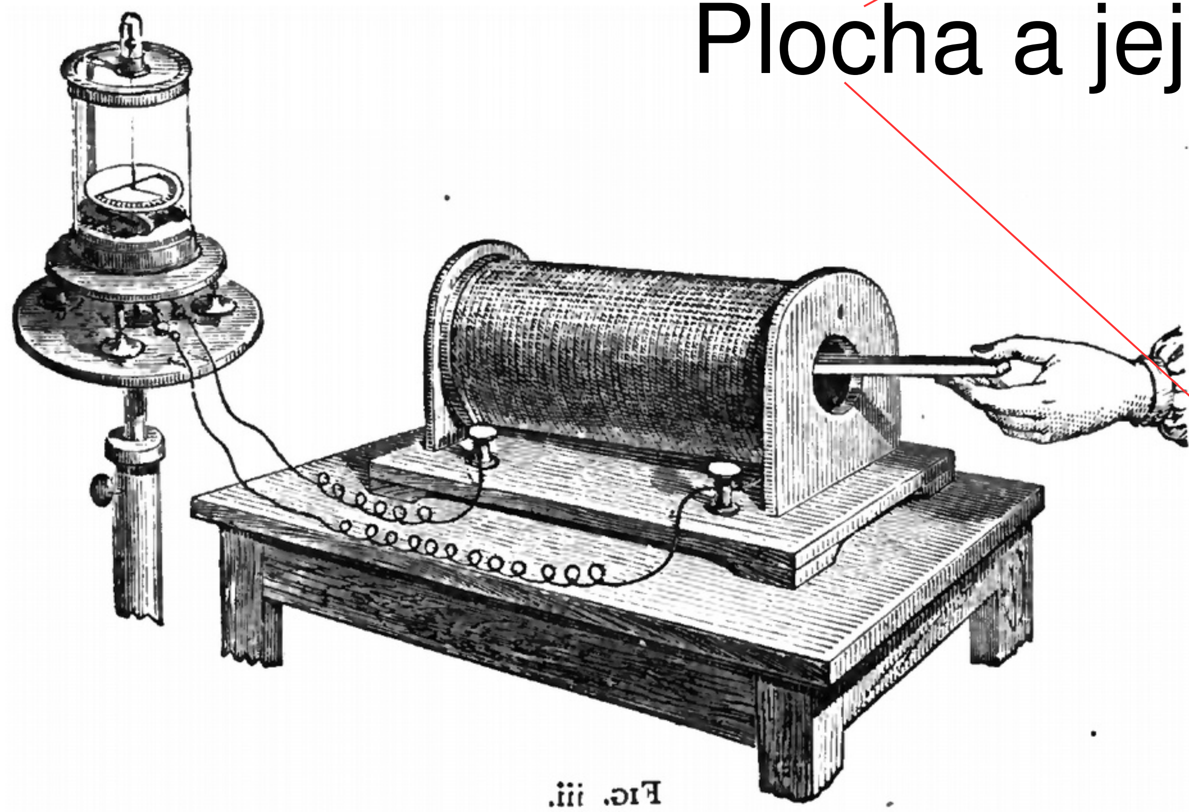
= proud

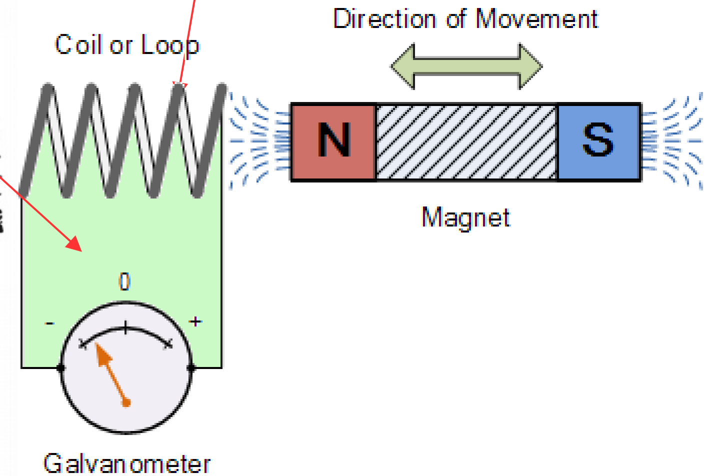


Elektromagnetická indukce

E = - rychlost změny B

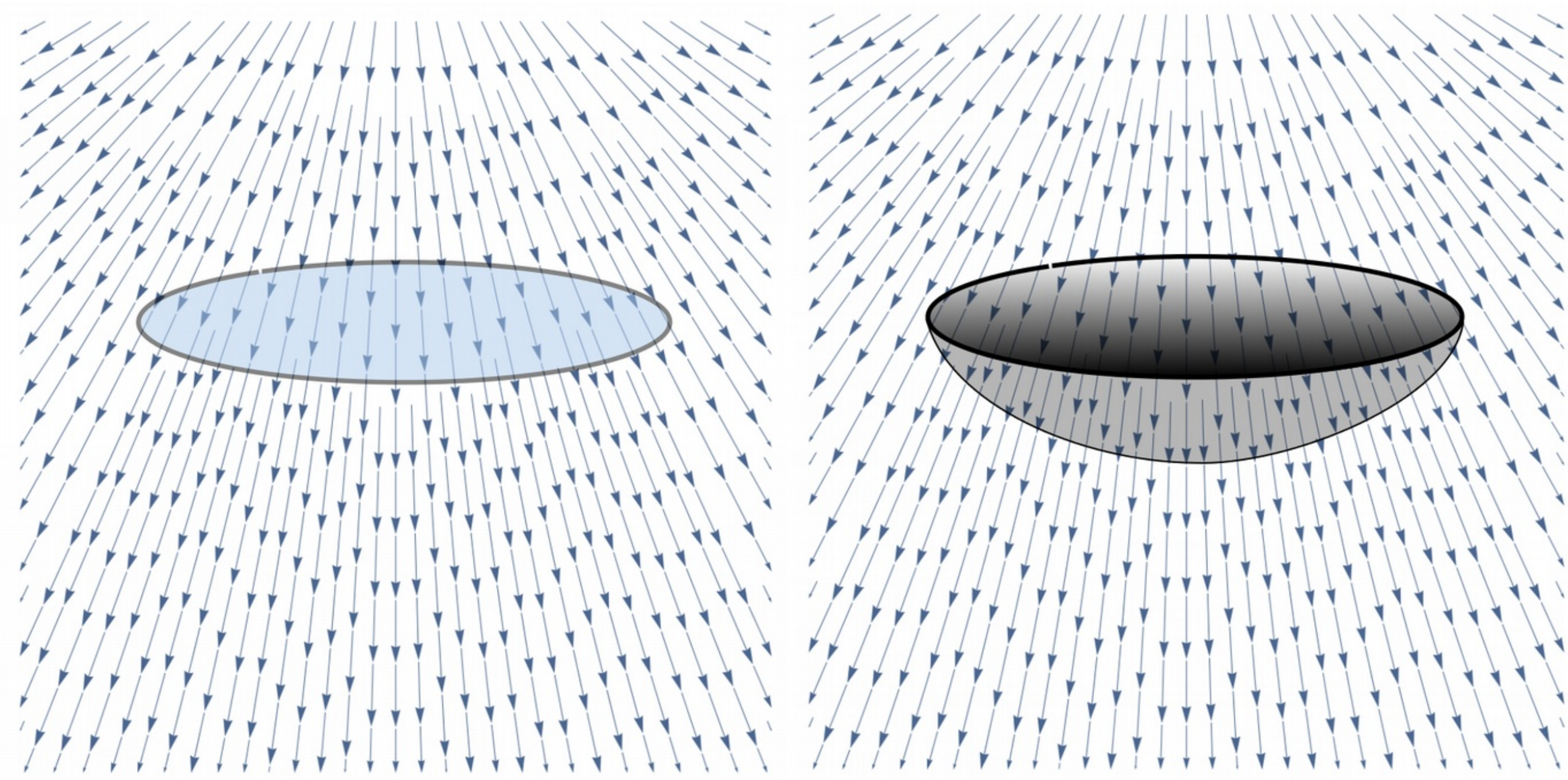
Plocha a její obvod





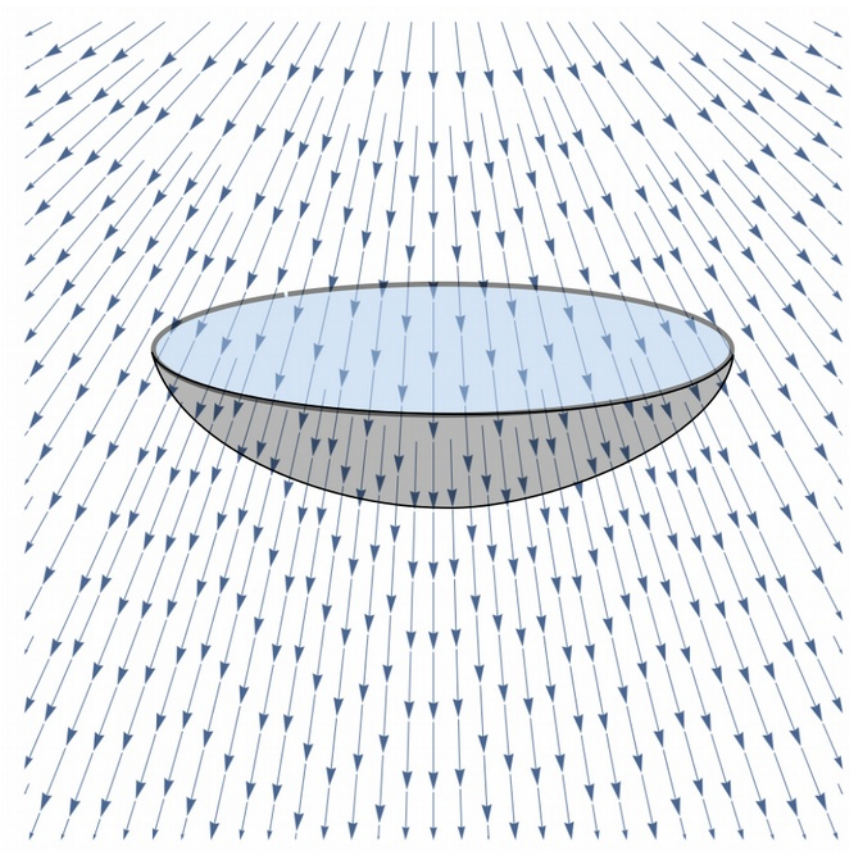
zdroj:www.electronics-tutorials.ws

Jakou plochu ?

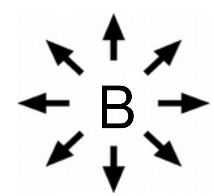


- Kupodivu na tom nezáleží !

Invariance magnetického toku



- Obě plochy sdílejí společný okraj
- Vymezují tedy objem mezi nimi
- Magnetické pole ovšem splňuje



$= 0$

- Co šedivou plochou vyteče
  to modrou přiteče

Na volbě plochy smyčkou nesejde !

Před Maxwellem:

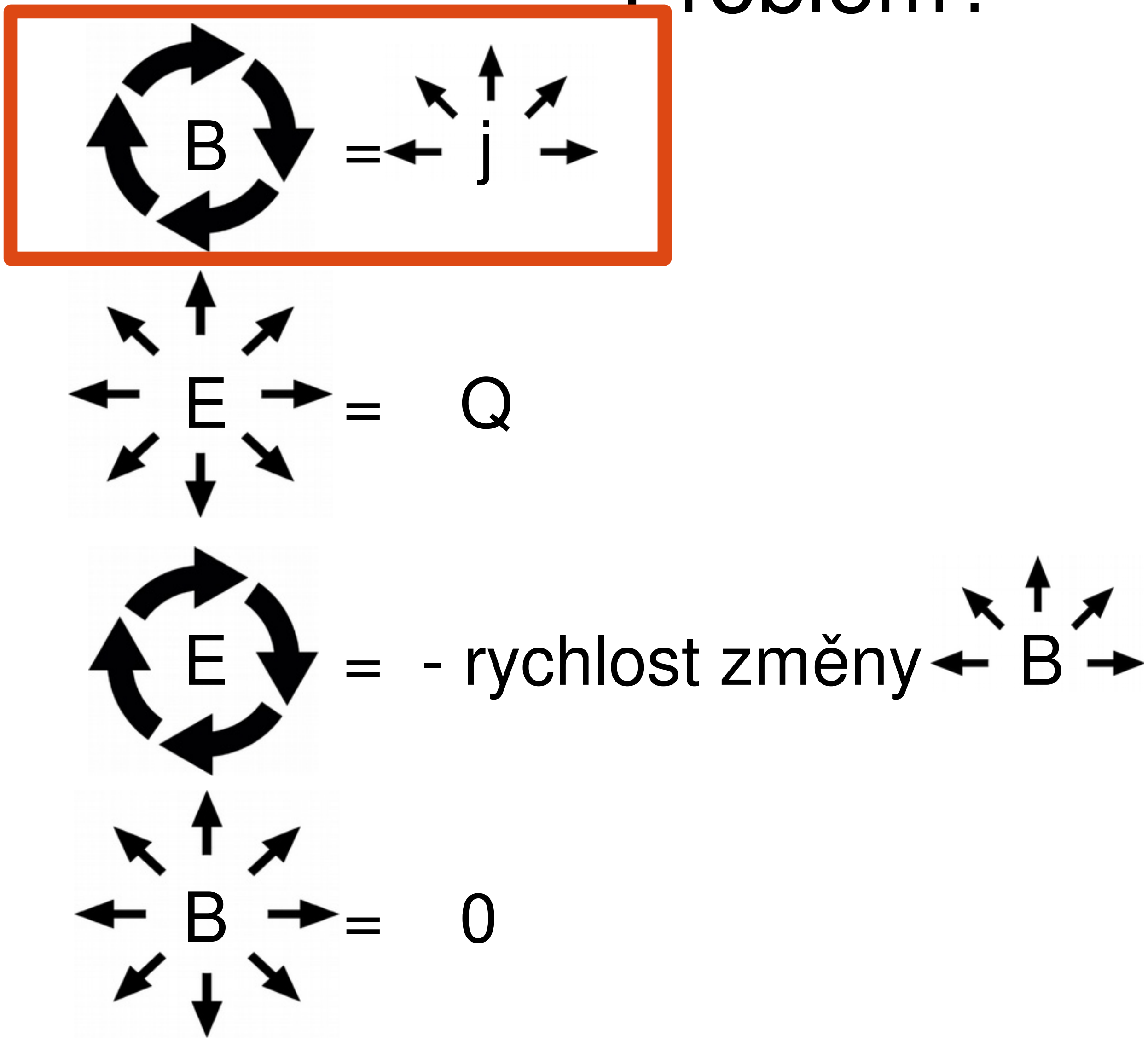
B = j

E = Q

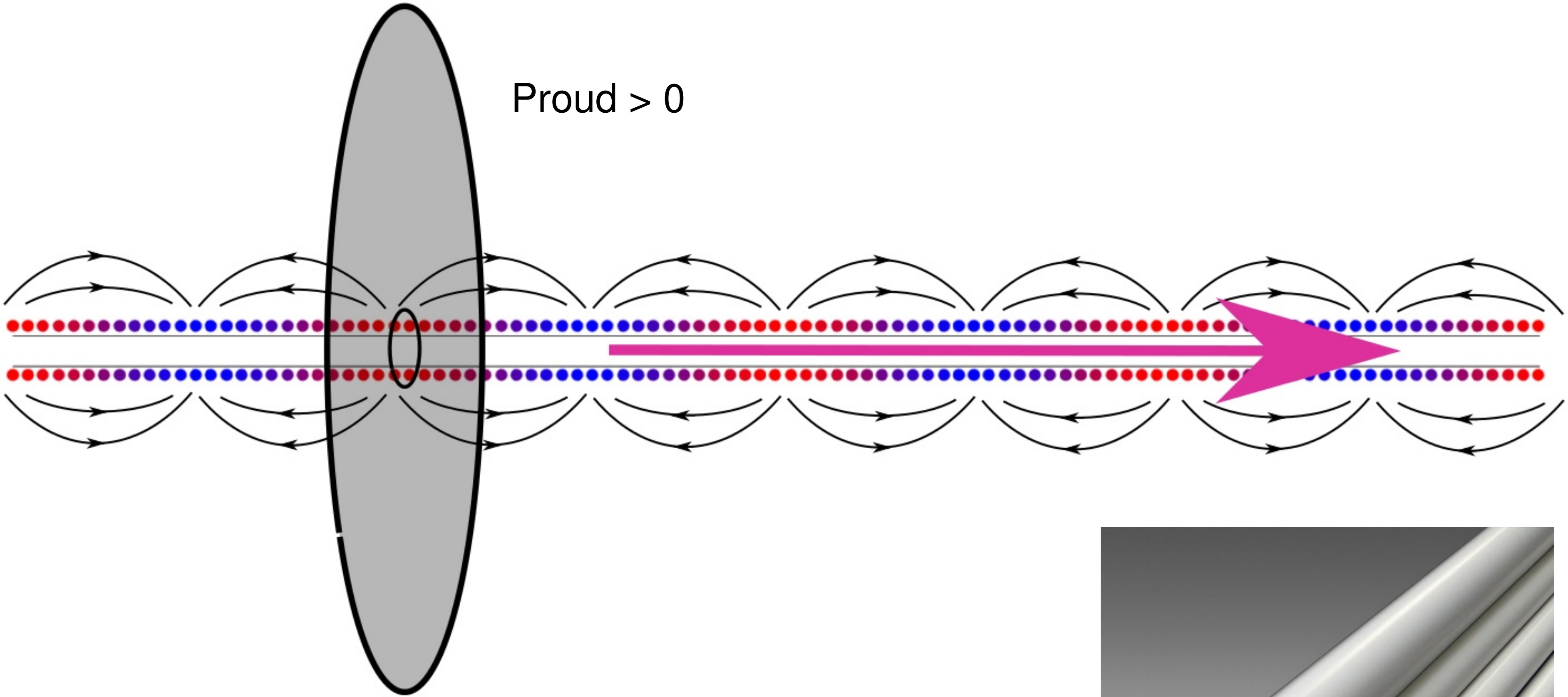
E = - rychlost změny B

B = 0 !! Bez nábojů a proudů není E a B

Problém?



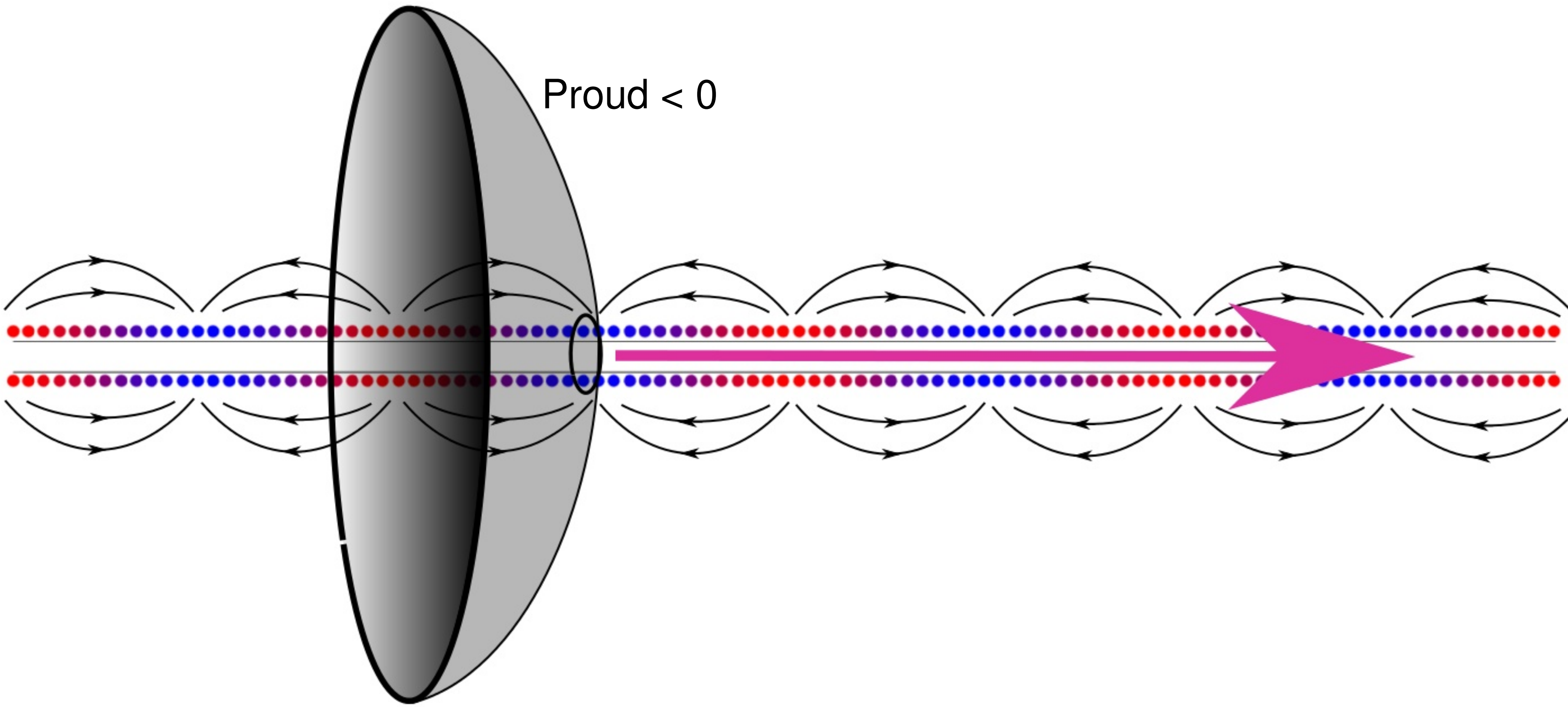
Problém !



Cirkulace magnetického pole by měla být dána proudy

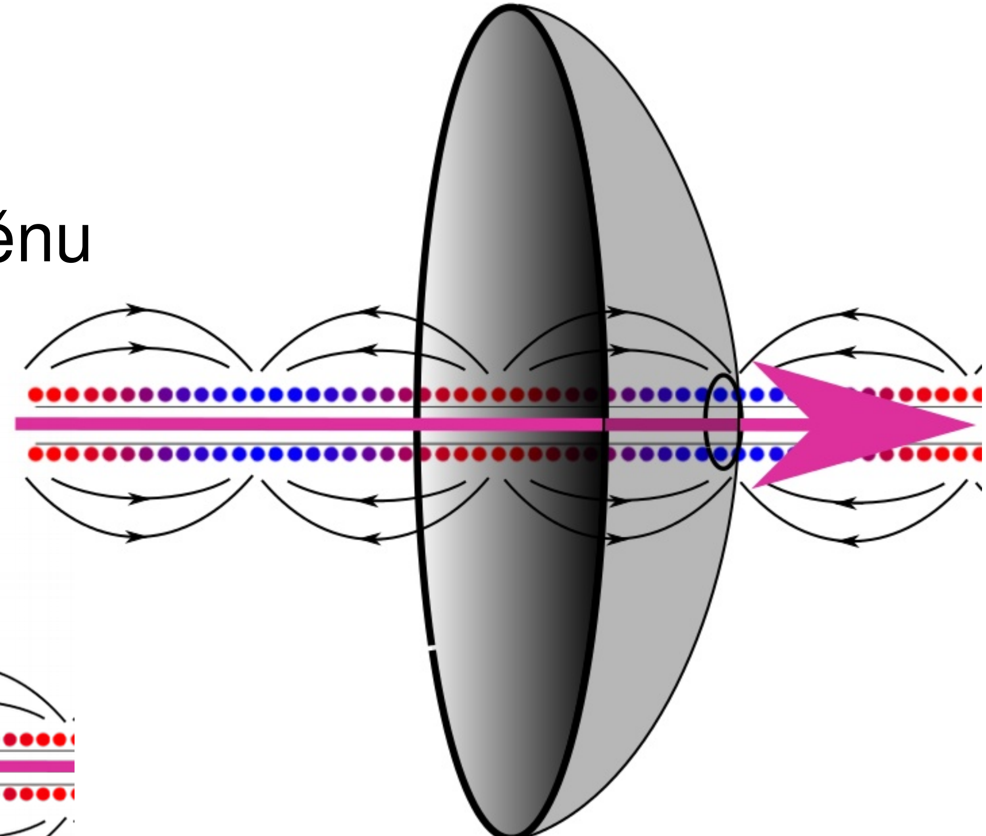
(ale kterými ?)

Problém !



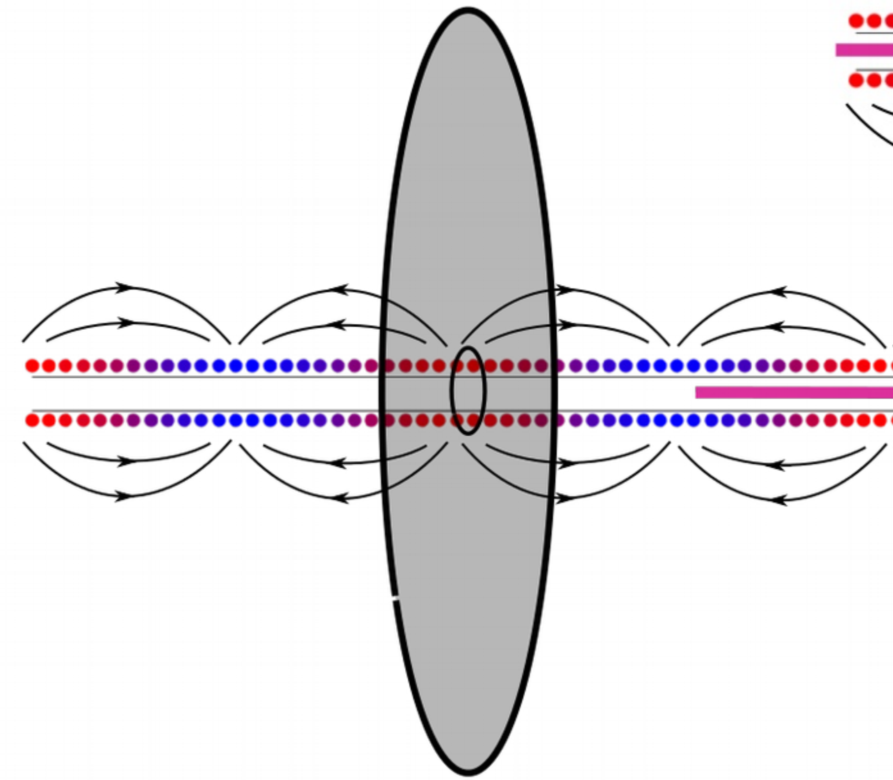
Maxwell:

přidejte k proudu ještě změnu toku elektrického pole



proud > 0

změna toku E < 0



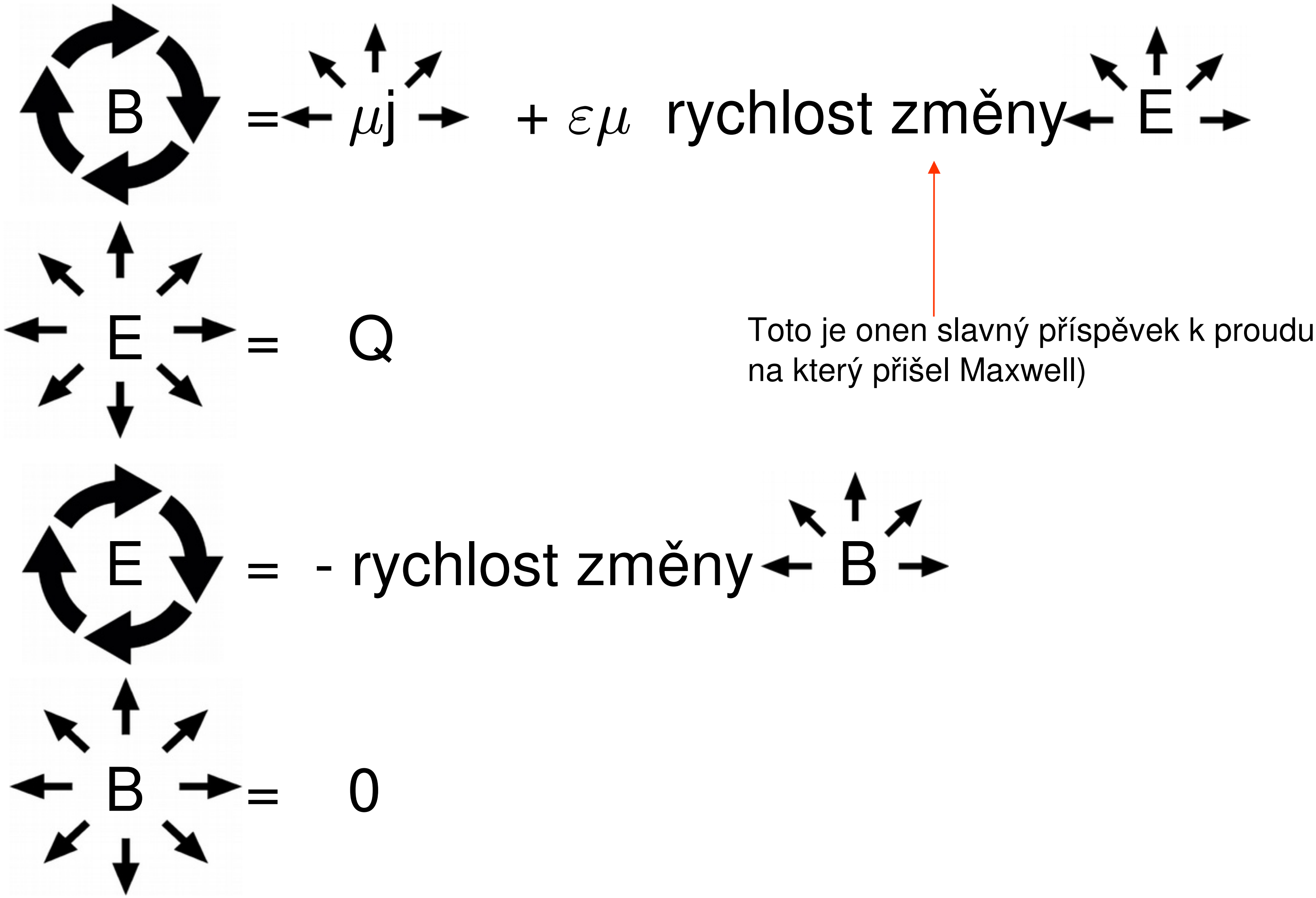
proud > 0

změna toku E < 0

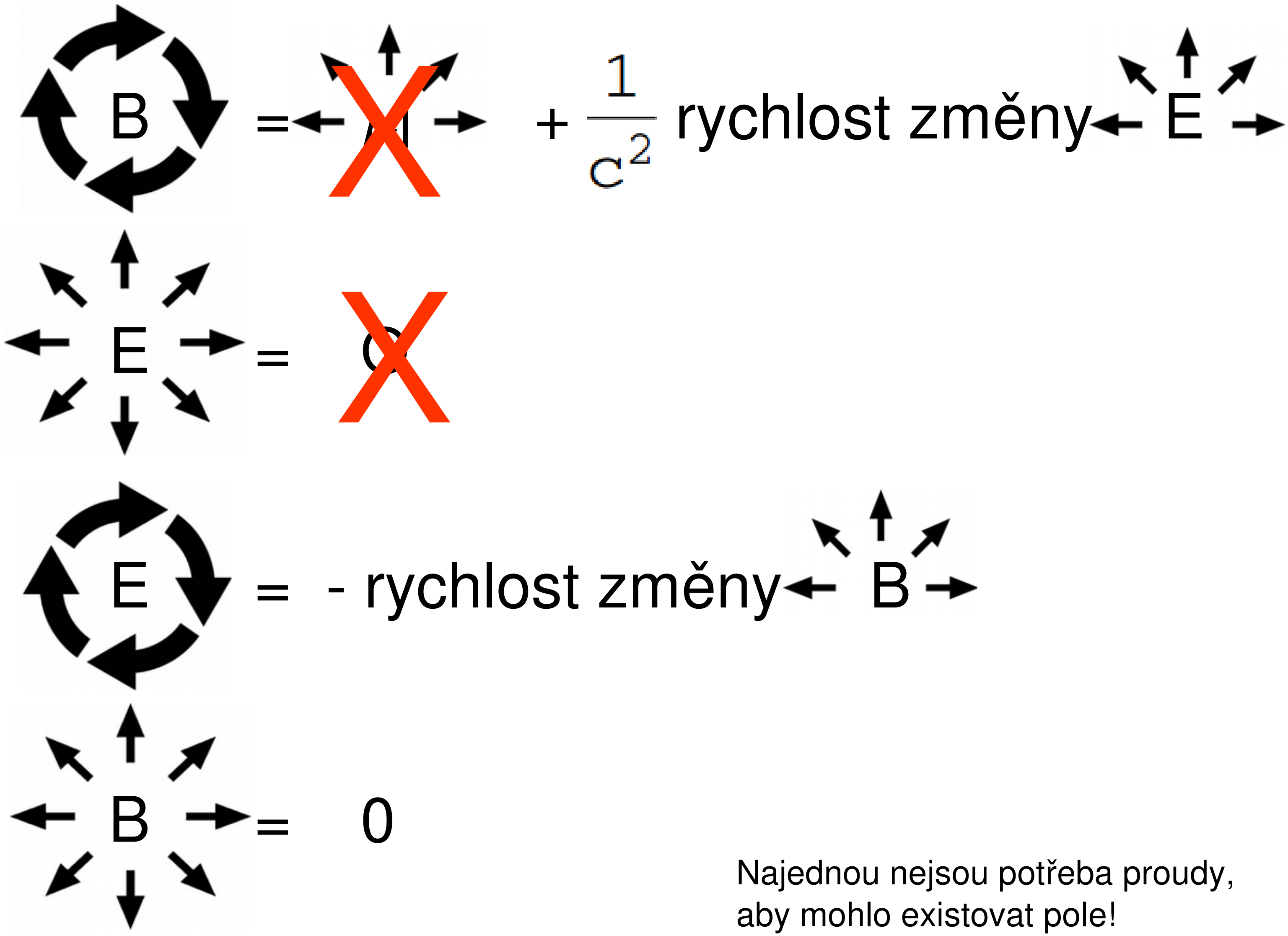
Mimochodem:

Zachování elektrického náboje

Maxwellovy rovnice (schematicky)

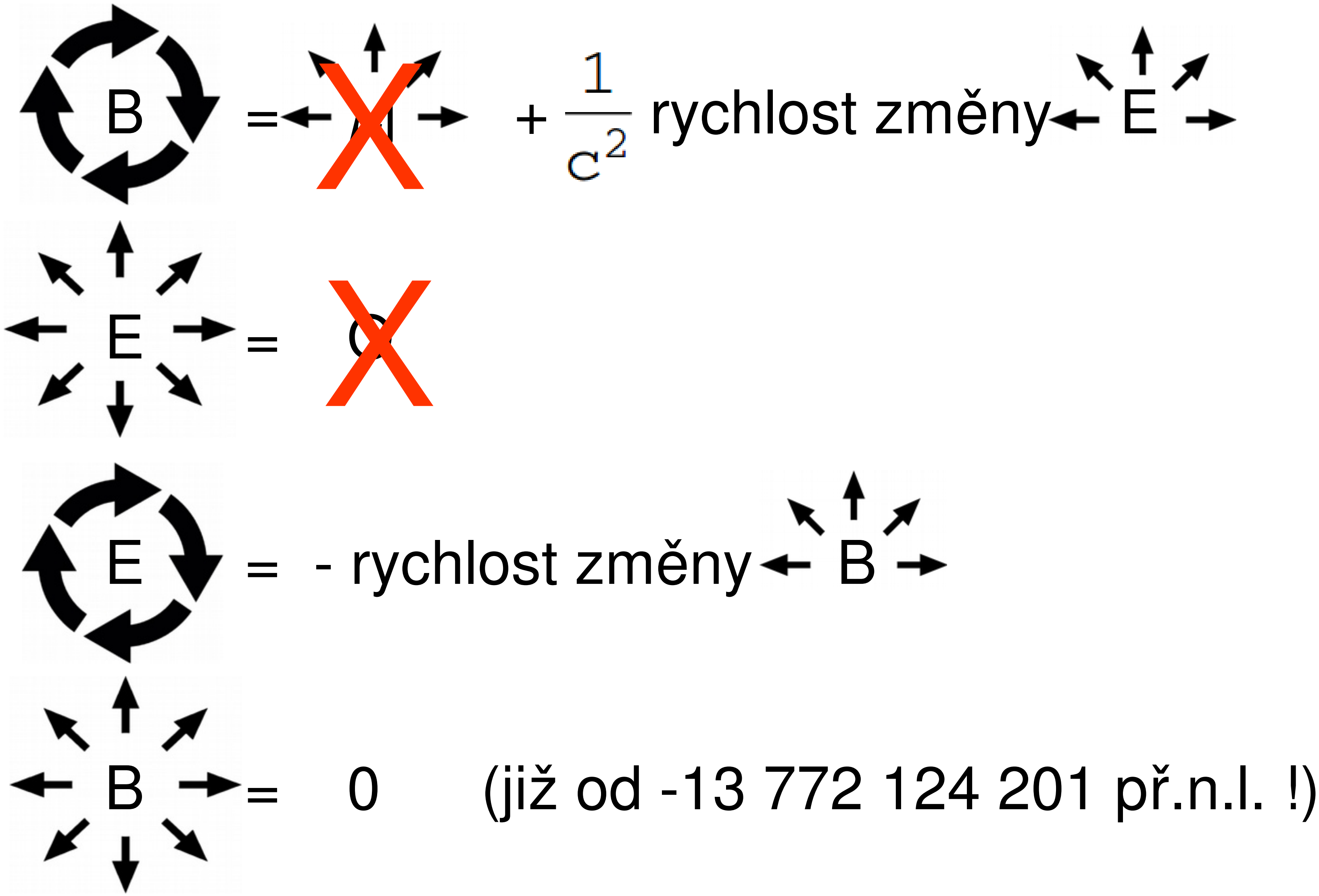


Maxwellovy vlny !



Najednou nejsou potřeba proudy,
aby mohlo existovat pole!

Maxwellovy vlny !

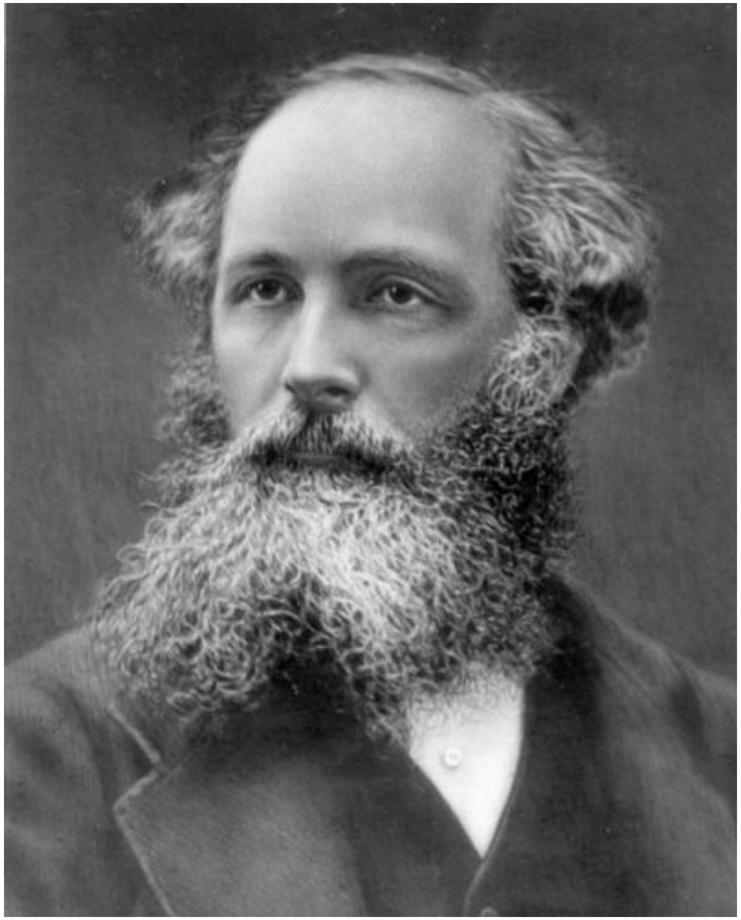


J. C. Maxwell

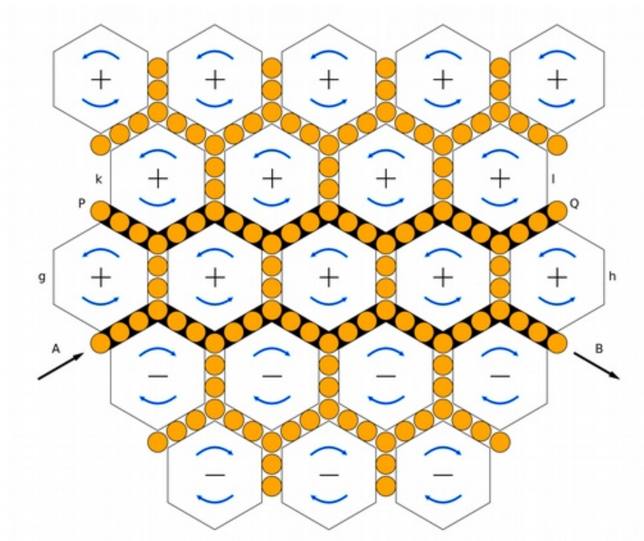
Another theory of electricity
– which I prefer
– denies action at a distance
– and attributes electric action to
– tensions and pressures
– in an all-pervading medium

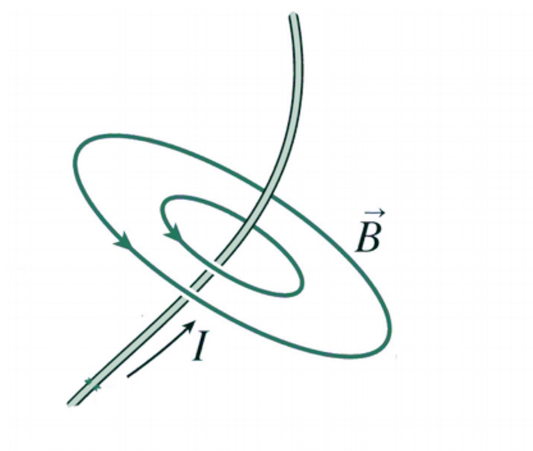
these stresses being the same in kind with those familiar to engineers, and the medium being identical with that in which light is supposed to be propagated

Shrnutí: elekromagnetické pole si lze představit jako „deformace“ pružného média. Změna v rozložení nábojů a proudů vede ke změně pole, která se postupně, rychlostí světla, šíří dále do prostoru.



Maxwellův mechanický model





-- Rovnice EM pole představovaly
~1850 ze 3/4 vyplněnou křížovku

-- známá políčka představovala "pomalé" jevy

-- kromě tajenky ale nebylo jasné ani zadání / jazyk

-- mechanický model
(vždyť napsal "On the Equilibrium of Elastic Solids")

-- už delší dobu se hledalo řešení s "vlnami"

-- pečlivým studiem by na ně přišel někdo další

-- "dimenzionální analýza" by brzy provalila c^2
(opět Maxwell)

Equations of Currents.

(62) It is known from experiment that the motion of a magnetic pole in the electromagnetic field in a closed circuit cannot generate work unless the circuit which the pole describes passes round an electric current. Hence, except in the space occupied by the electric currents,

$$\alpha dx+\beta dy+\gamma dz=d\phi \qquad (31)$$

a complete differential of ϕ, the magnetic potential.

The quantity ϕ may be susceptible of an indefinite number of distinct values, according to the number of times that the exploring point passes round electric currents in its course, the difference between successive values of ϕ corresponding to a passage completely round a current of strength c being $4\pi c$.

Hence if there is no electric current,

$$dy-\frac{d\beta}{dz}=0\,;$$

but if there is a current p',

$$\frac{d\gamma}{dy}-\frac{d\beta}{dz}=4\pi p'.$$

Similarly,

$$\left.\begin{aligned}\frac{d\gamma}{dy}-\frac{d\beta}{dz}&=4\pi p',\\ \frac{d\alpha}{dz}-\frac{d\gamma}{dx}&=4\pi q',\\ \frac{d\beta}{dx}-\frac{d\alpha}{dy}&=4\pi r'.\end{aligned}\right\} \qquad (C)$$

We may call these the Equations of Currents.

$$\left.\begin{aligned} p' &= p + \frac{d f}{dt} \\ q' &= q + \frac{d g}{dt} \\ r' &= r + \frac{d h}{dt} \end{aligned}\right\} \rightarrow \mathbf{J} = \mathbf{j} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\left.\begin{aligned} P &= \mu\left(\gamma\frac{dy}{dt} - \beta\frac{dz}{dt}\right) - \frac{dF}{dt} - \frac{d\Psi}{dx} \\ Q &= \mu\left(\alpha\frac{dz}{dt} - \gamma\frac{dx}{dt}\right) - \frac{dG}{dt} - \frac{d\Psi}{dy} \\ R &= \mu\left(\beta\frac{dx}{dt} - \alpha\frac{dy}{dt}\right) - \frac{dH}{dt} - \frac{d\Psi}{dz} \end{aligned}\right\} \rightarrow \mathbf{E} = \mu(\mathbf{v} \times \mathbf{H}) - \frac{\partial \mathbf{A}}{\partial t} - \nabla\varphi$$

$$\left.\begin{aligned} \mu\alpha &= \frac{dH}{dy} - \frac{dG}{dz} \\ \mu\beta &= \frac{dF}{dz} - \frac{dH}{dx} \\ \mu\gamma &= \frac{dG}{dx} - \frac{dF}{dy} \end{aligned}\right\} \rightarrow \mu\mathbf{H} = \nabla \times \mathbf{A}$$

$$\left.\begin{aligned} P &= k f \\ Q &= k g \\ R &= k h \end{aligned}\right\} \rightarrow \varepsilon\mathbf{E} = \mathbf{D}$$

$$\left.\begin{aligned} P &= -\zeta p \\ Q &= -\zeta q \\ R &= -\zeta r \end{aligned}\right\} \rightarrow \sigma\mathbf{E} = \mathbf{j}$$

$$\left.\begin{aligned} \frac{d\gamma}{dy} - \frac{d\beta}{dz} &= 4\pi p' \\ \frac{d\alpha}{dz} - \frac{d\gamma}{dx} &= 4\pi q' \\ \frac{d\beta}{dx} - \frac{d\alpha}{dy} &= 4\pi r' \end{aligned}\right\} \rightarrow \nabla \times \mathbf{H} = \mathbf{J}$$

$$e + \frac{d f}{dx} + \frac{d g}{dy} + \frac{d h}{dz} = 0 \rightarrow -\rho = \nabla \cdot \mathbf{D}$$

$$\frac{de}{dt} + \frac{dp}{dx} + \frac{dq}{dy} + \frac{dr}{dz} = 0 \rightarrow -\frac{\partial \rho}{\partial t} = \nabla \cdot \mathbf{j}$$

Hence magnetic disturbances propagated through the electromagnetic field agree with light in this, that the disturbance at any point is transverse to the direction of propagation, and such waves may have all the properties of polarized light.

(96) The only medium in which experiments have been made to determine the value of k is air, in which $\mu=1$, and therefore, by equation (46),

$$V=v. \qquad \ldots \ldots \ldots \ldots \qquad (72)$$

By the electromagnetic experiments of MM. WEBER and KOHLRAUSCH *,

$$v=310,740,000 \text{ metres per second}$$

is the number of electrostatic units in one electromagnetic unit of electricity, and this, according to our result, should be equal to the velocity of light in air or vacuum.

The velocity of light in air, by M. FIZEAU'S † experiments, is

$$V=314,858,000;$$

according to the more accurate experiments of M. FOUCAULT ‡,

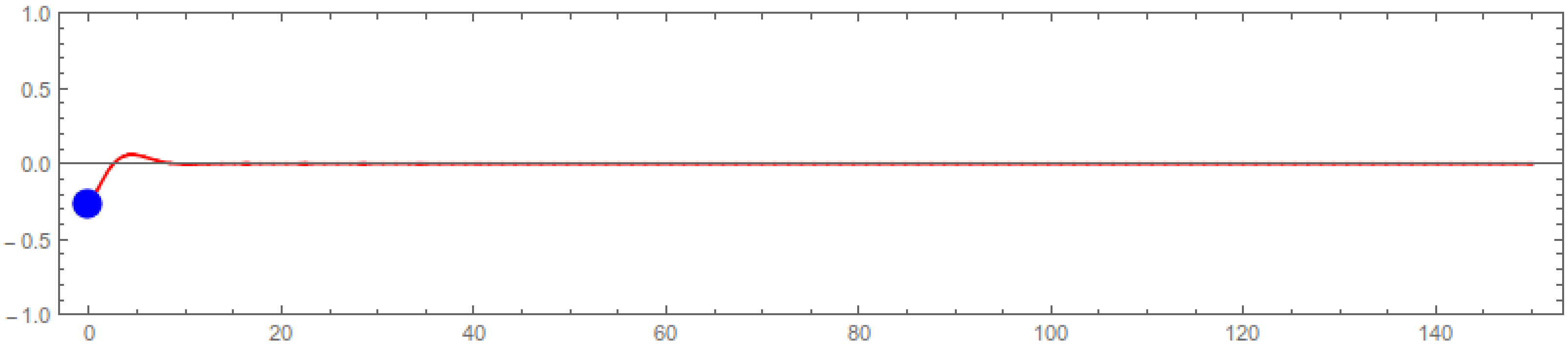
$$V=298,000,000.$$

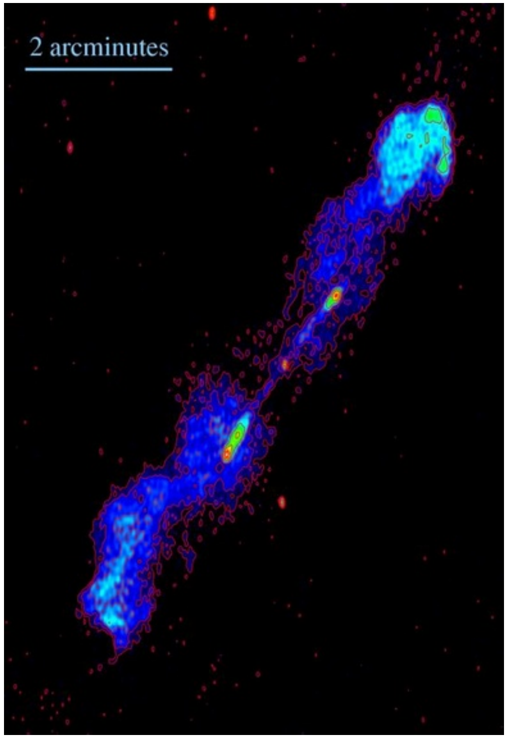
The velocity of light in the space surrounding the earth, deduced from the coefficient of aberration and the received value of the radius of the earth's orbit, is

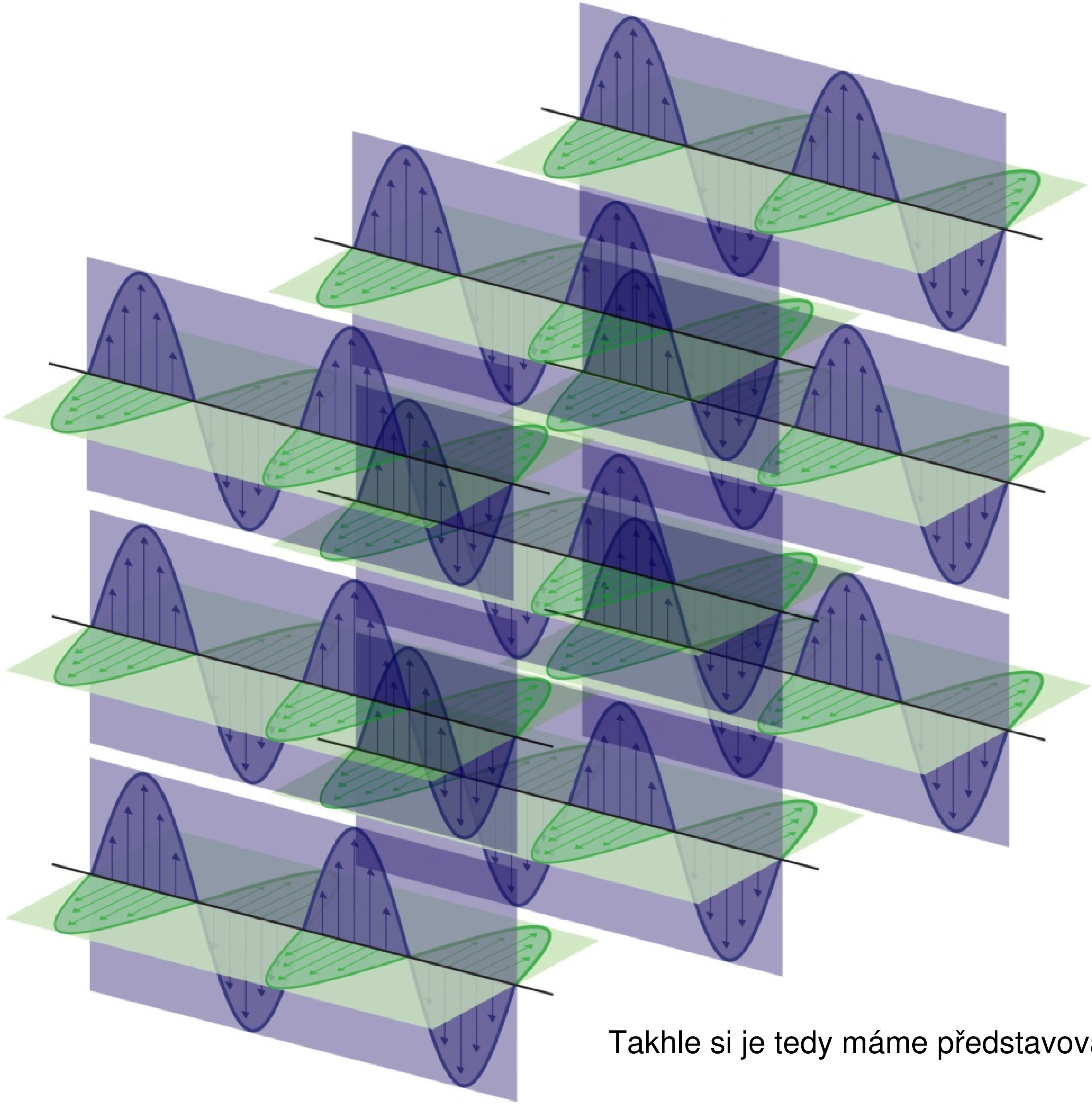
$$V=308,000,000.$$

(97) Hence the velocity of light deduced from experiment agrees sufficiently well with the value of v deduced from the only set of experiments we as yet possess. The value of v was determined by measuring the electromotive force with which a condenser of known capacity was charged, and then discharging the condenser through a galvanometer, so as to measure the quantity of electricity in it in electromagnetic measure. The only use made of light in the experiment was to see the instruments. The value of V found by M. FOUCAULT was obtained by determining the angle through which a revolving mirror turned, while the light reflected from it went and returned along a measured course. No use whatever was made of electricity or magnetism.

Vlny – no a co ?

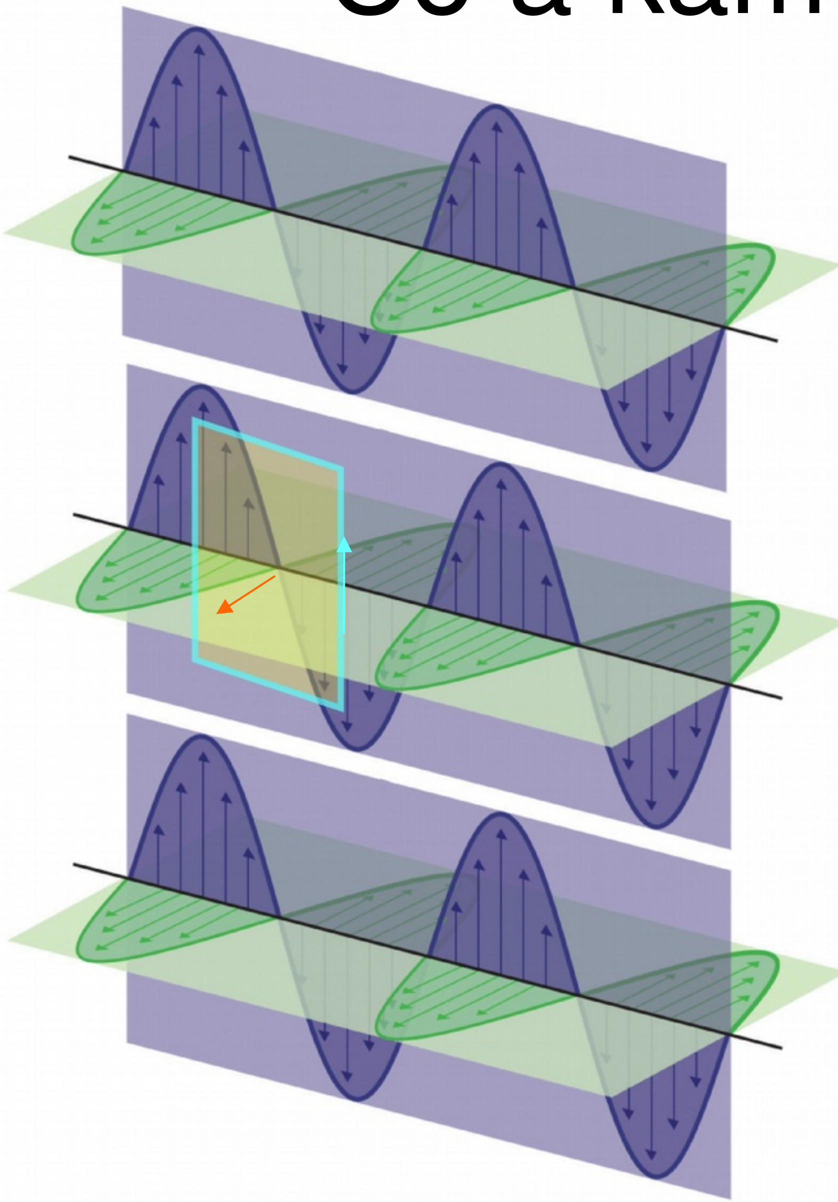


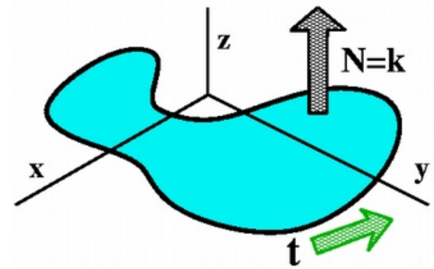




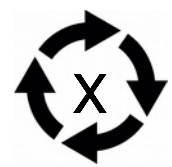
Takhle si je tedy máme představovat?

Co a kam letí ?





Stokes !



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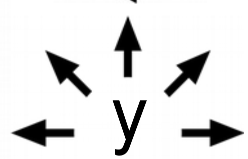
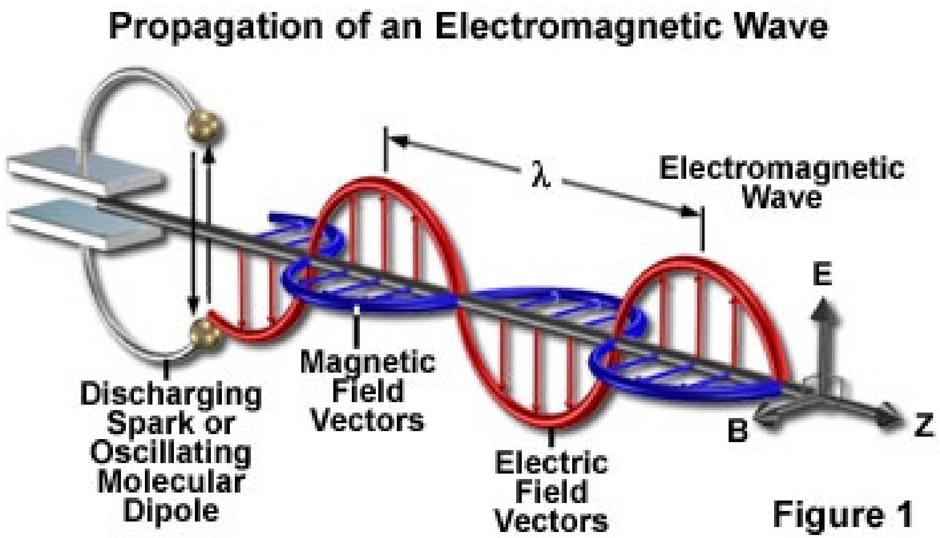


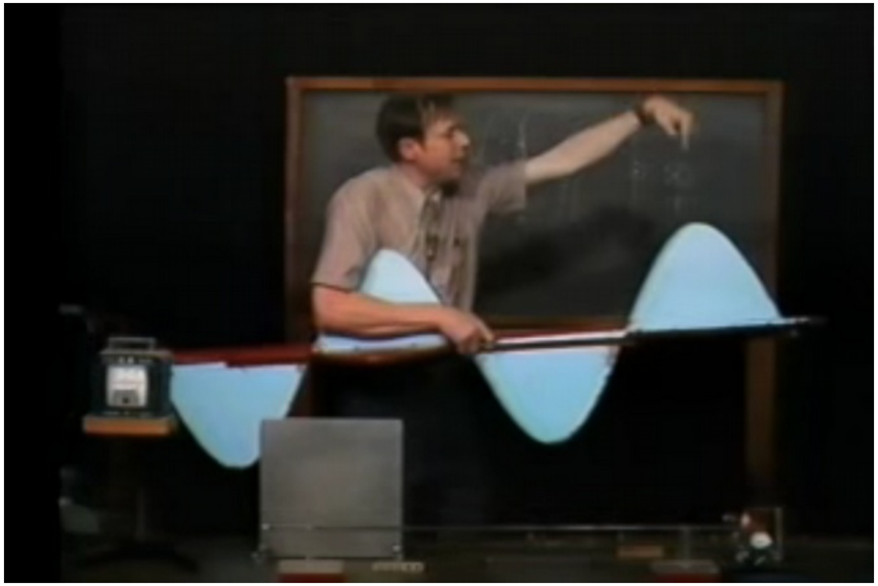
se mění:

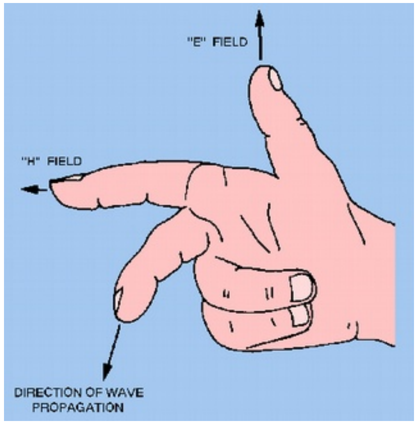
roste → E, B

klesá ← B, E

Takže, co to jsou ty EM vlny?







Elektromagnetické vlny

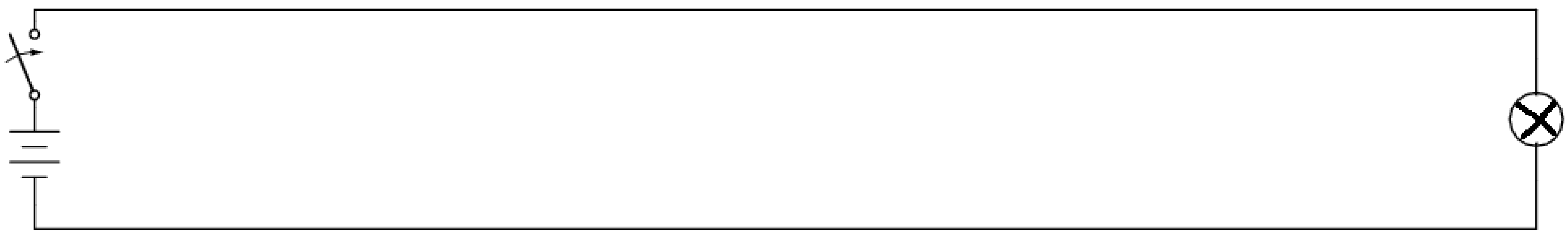
- ano, jsou to **vlny**
  - mají rychlost a směr šíření
  - frekvenci odpovídá vlnová délka
  - přenášejí energii a hybnost

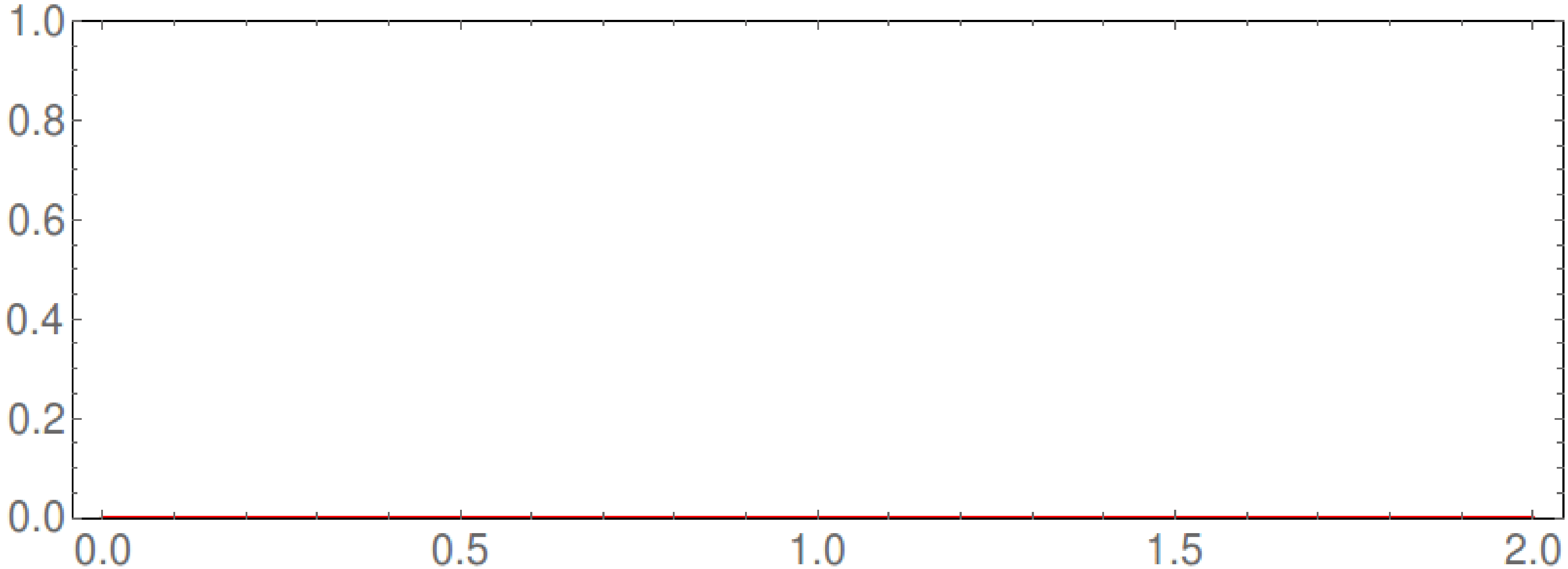
- jsou to stupně volnosti elektromagnetického pole
  (něco, co zbyde, když náboje a proudy zaniknou)

- Maxwellova teorie říká jak
  - **zdroje** vytvářejí EM pole
  - toto pole se **šíří** (na delší vzdálenosti v podobě vln)
  - ovlivňuje „**detektor**“

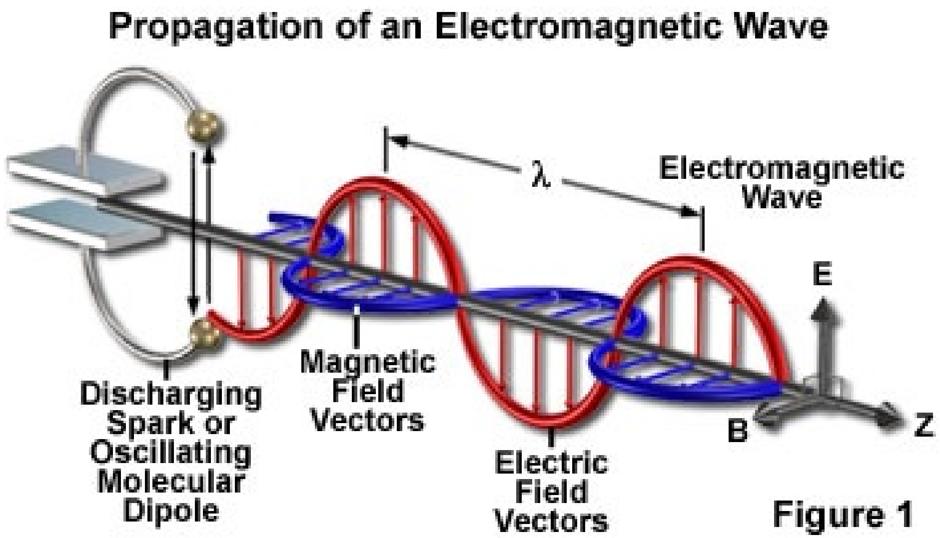
  (někdy se toto působení zdá okamžité, jindy to trvá)

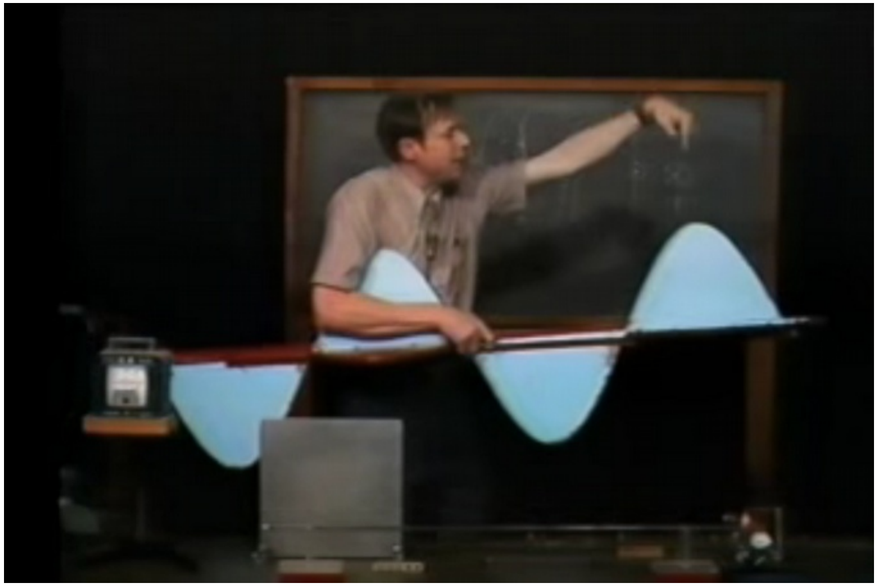
Obvod s žárovkou (se nezdá)

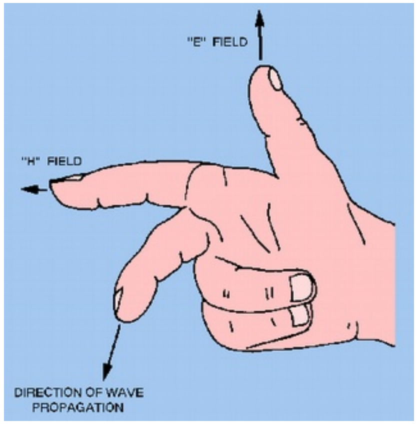




Takže, co to jsou ty EM vlny?







Mocniny vzdálenosti

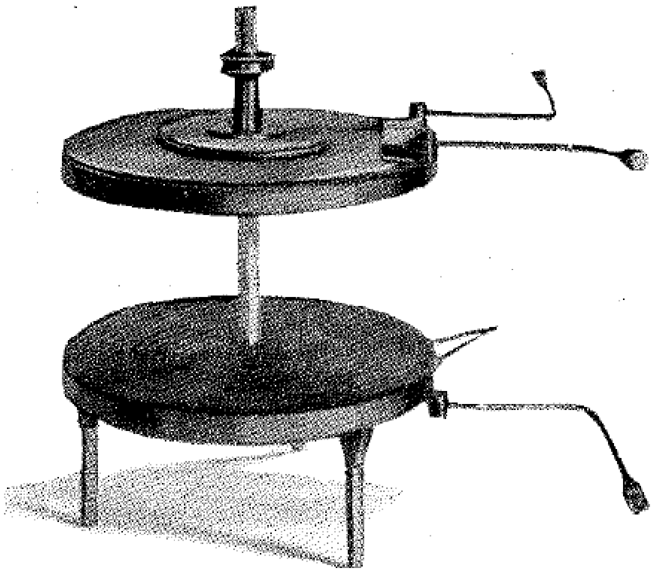
Pole	magnetické	elektrické	elektomagnetické
	1T	100 000V/m	40 V/m
1km	1/100 000 000	100 pV/m	1mV/m
10km	1/100 000 000 000	0.1 pV/m	0.1mV/m
	magn. pole země	(ve Vakuu)	

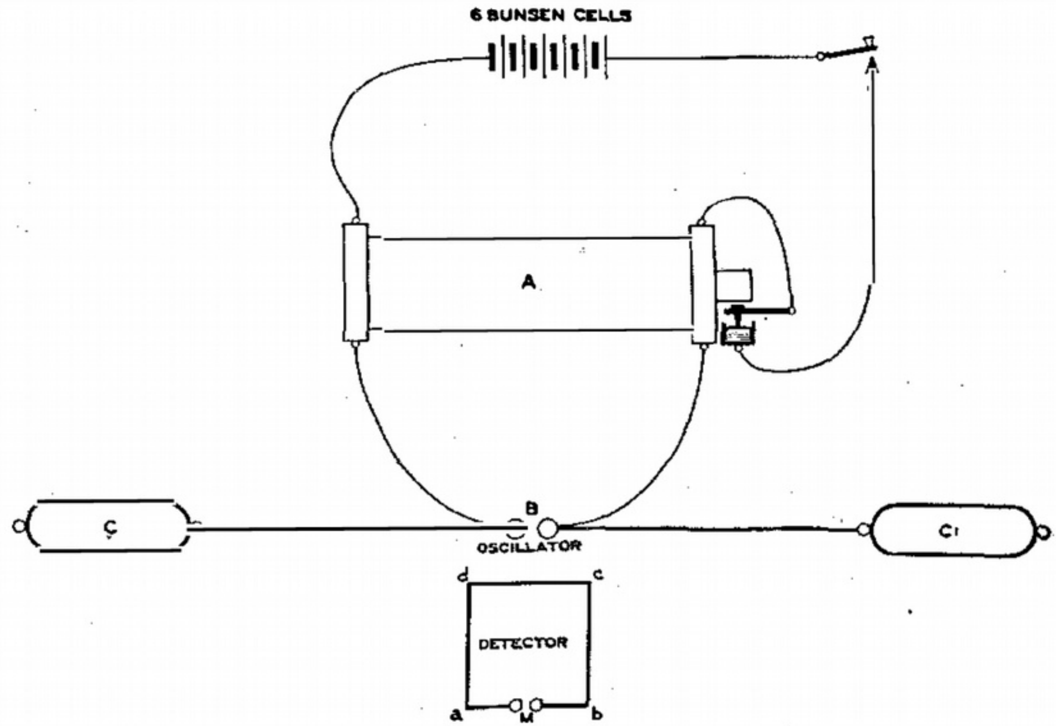
Mocniny vzdálenosti

Pole	magnetické	elektrické	elektomagnetické
	1T	100 000V/m	40 V/m
1km	1/100 000 000	1mV/m	1mV/m
10km	1/100 000 000 000	0.01mV/m	0.1mV/m
	magn. pole země	(ve Vakuu)	

Heinrich Hertz 1887





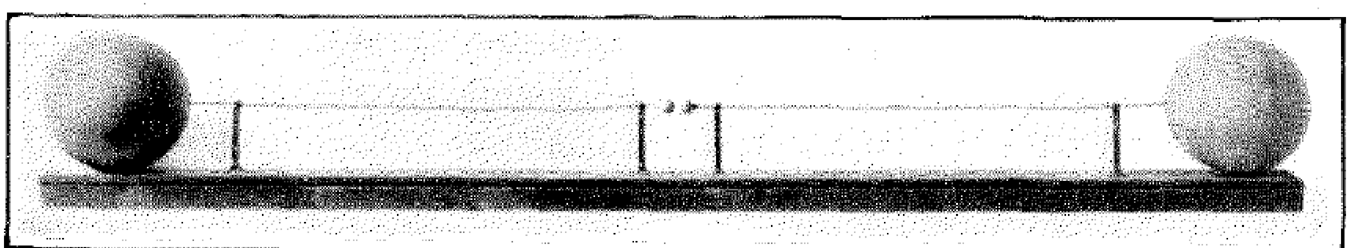
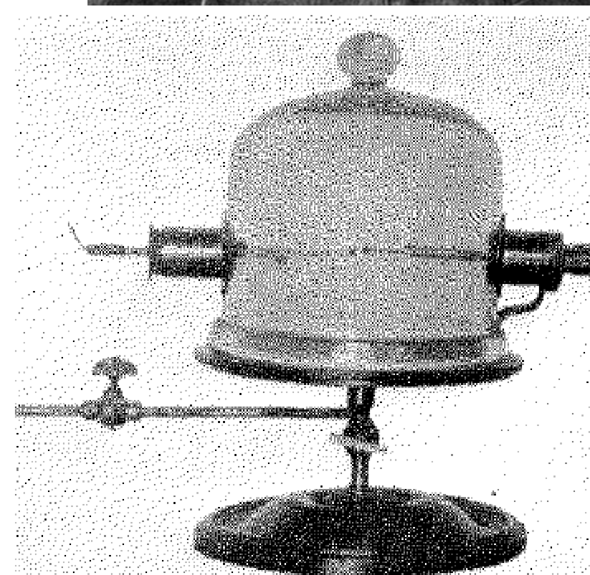


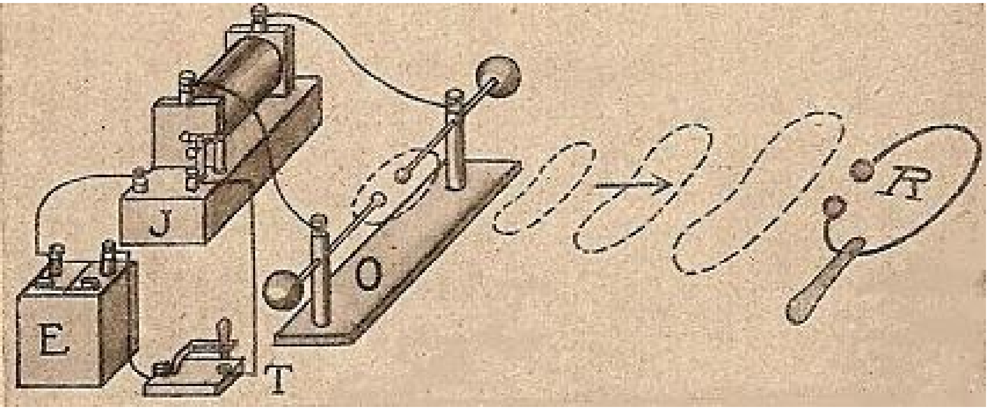
Figure 3—The First Oscillator of Hertz. Two copper wires, each 1 metre in length, supported on rods of sealing wax. The large spheres are of sheet zinc, and are 30 centimetres in diameter. Base 260 x 7.5 centimetres

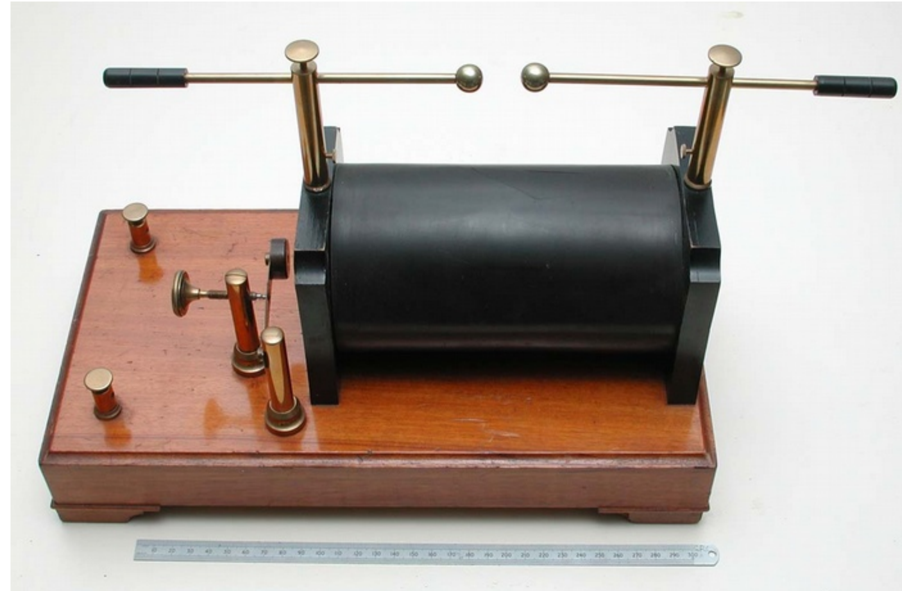
Heinrich Hertz 1886-7

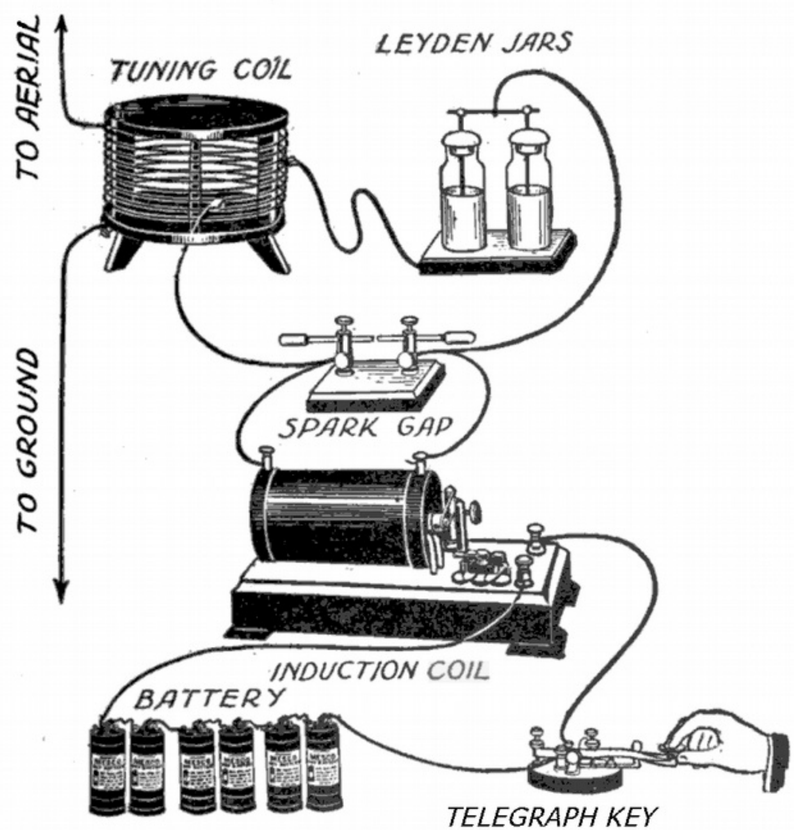
- as a detector the spark directly observed at the gap in a resonator,
- measured by the spark-micrometer (hot-wire galvanometer)
- determined the positions of nodes, anti-nodes, wavelength
- placed respectively at the principal foci of two parabolic mirrors
- up to a distance of about 16 metres
- the waves could penetrate a wooden door
- laws of reflection were proved
- refraction - prism of pitch (800kilogrammes)



Hertzovy vlny







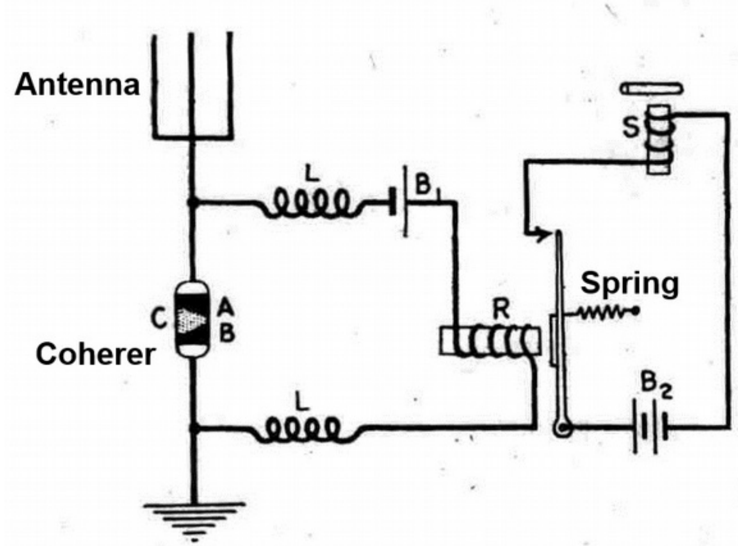


Fig. 101. Marconi 1896 Receiver.

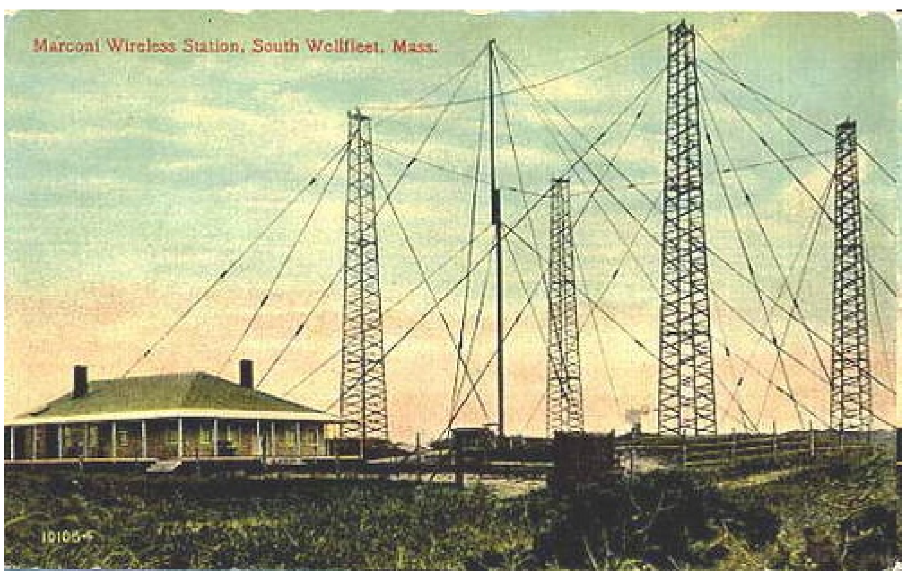
Guglielmo Marconi

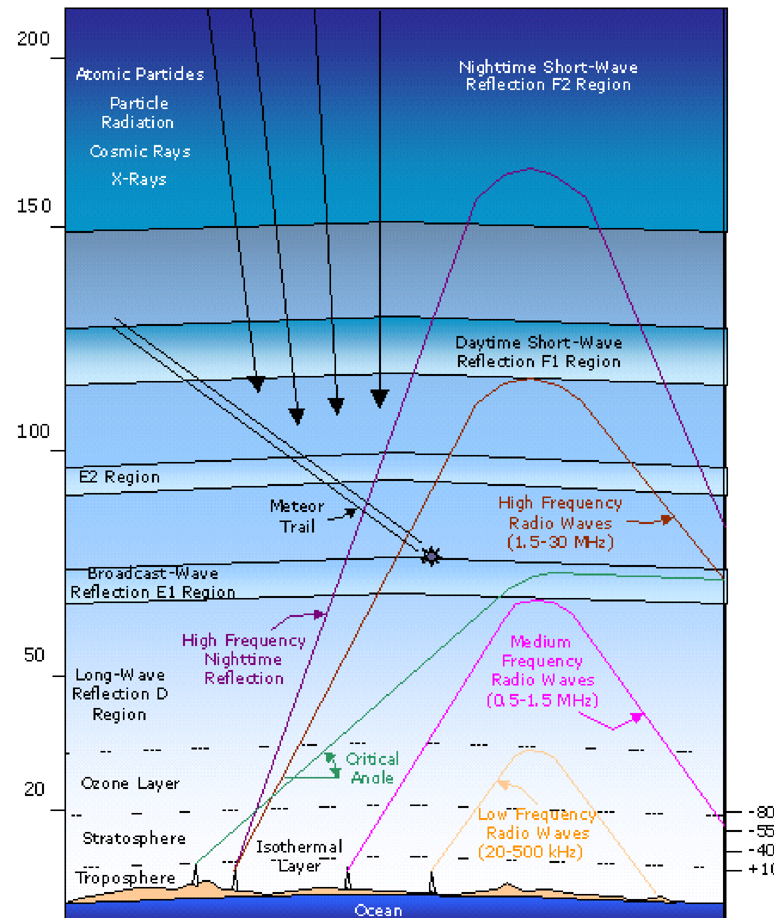
Wireless telegraphic communication

Nobel Lecture, December 11, 1909

I have also recently been able to confirm the statement made by Prof. Fleming in his book *The Principles of Electric Wave Telegraphy*, 1906, page 555, that with a power of 8 watts in the aerial it is possible to communicate to distances of over 100 miles.

On many occasions last winter, the S.S. "Caronia" of the Cunard Line, carrying a station utilizing about 1/2 kilowatt, when in the Mediterranean, off the coast of Sicily, failed to obtain communication with the Italian stations, but had no difficulty whatsoever in transmitting and receiving messages to and from the coasts of England and Holland, although these latter stations were considerably more than 1,000 miles away, and a large part of the continent of Europe and the Alps lay between them and the ship.

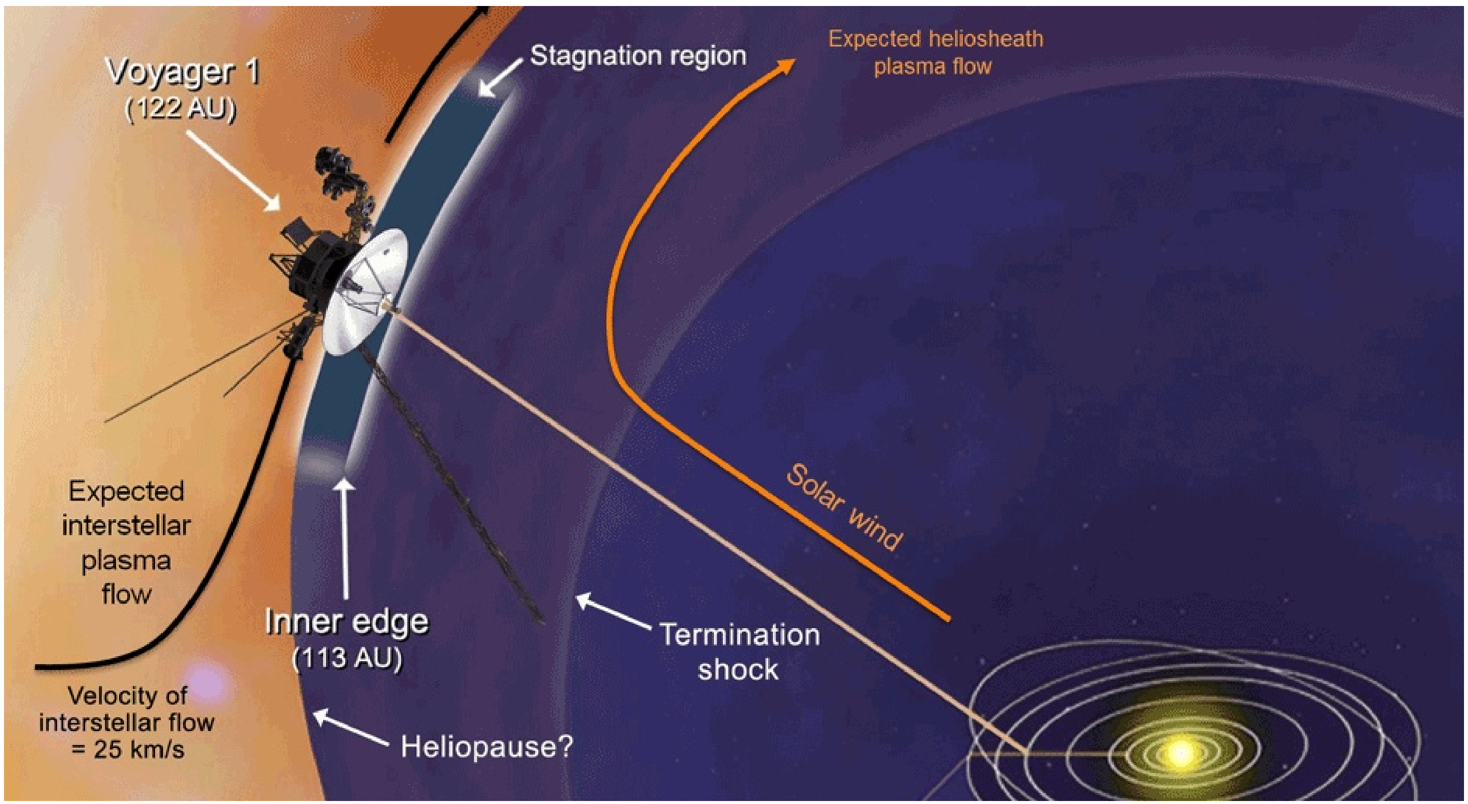




Voyager 1

T = 2012
P = 23 W
L = 18 000 000 000 km

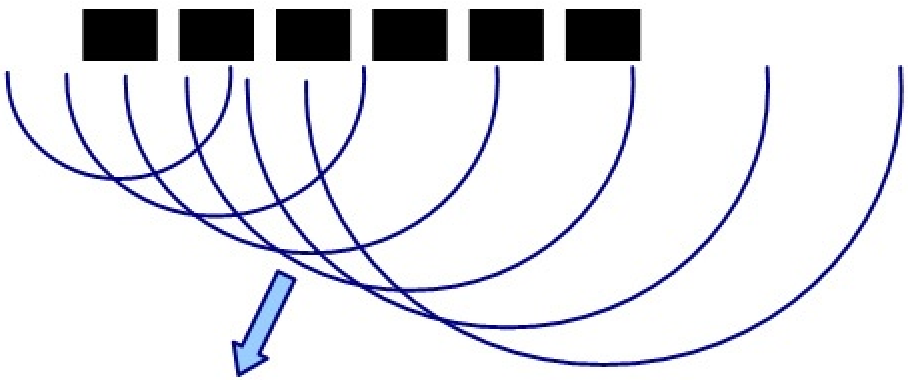
> I have also recently been able to confirm the statement made by Prof. Fleming in his book *The Principles of Electric Wave Telegraphy*, 1906, page 555, that with a power of 8 watts in the aerial it is possible to communicate to distances of over 100 miles.

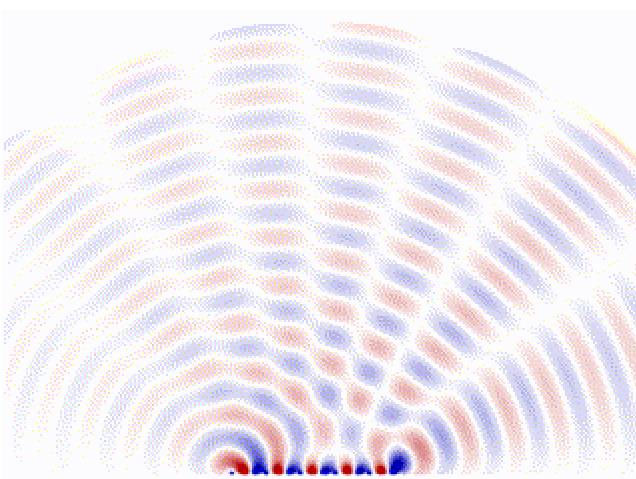


Karl Ferdinand Braun

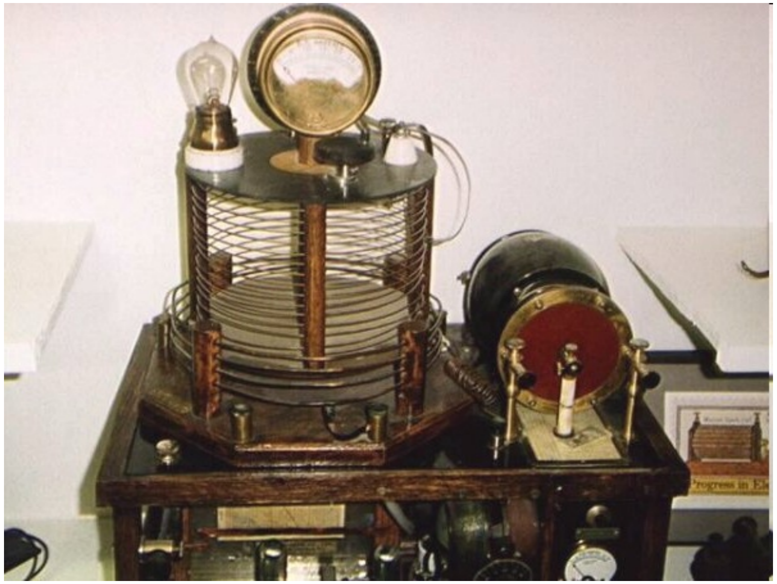
Wireless telegraphic communication

Nobel Lecture, December 11, 1909

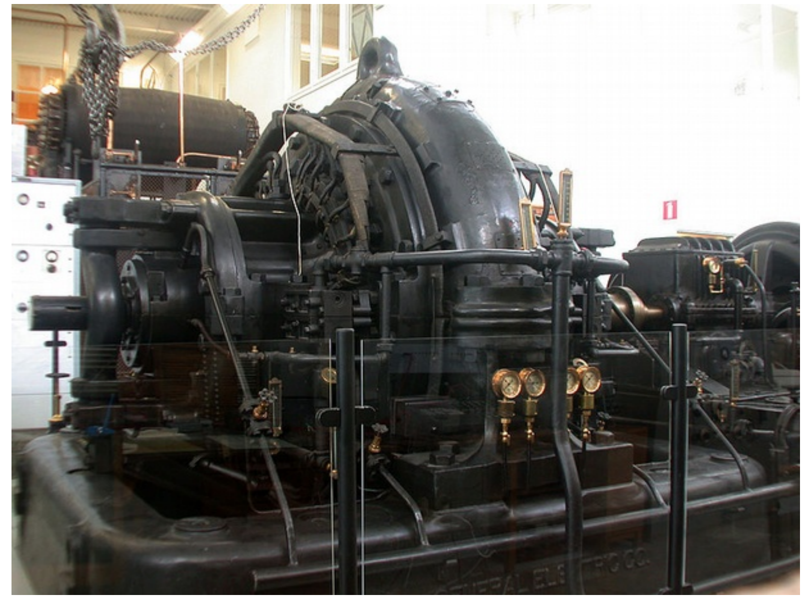




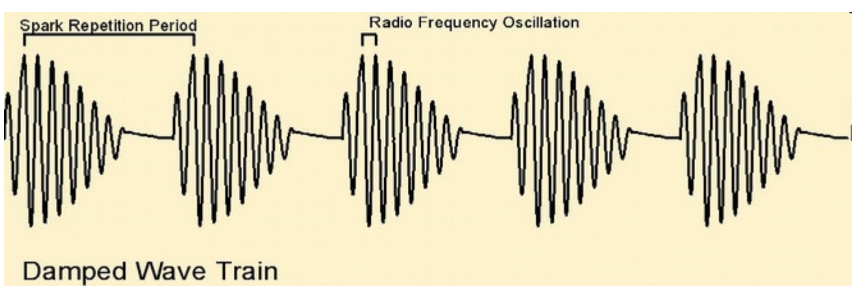
Počátky radiotelegrafie

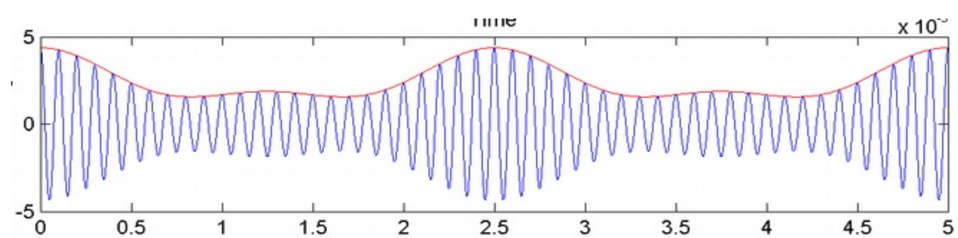


Jiskrový vysílač



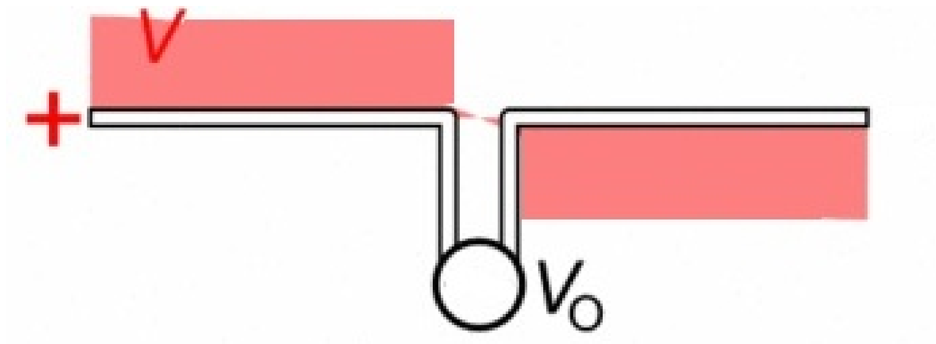
Alexandersonův alternátor

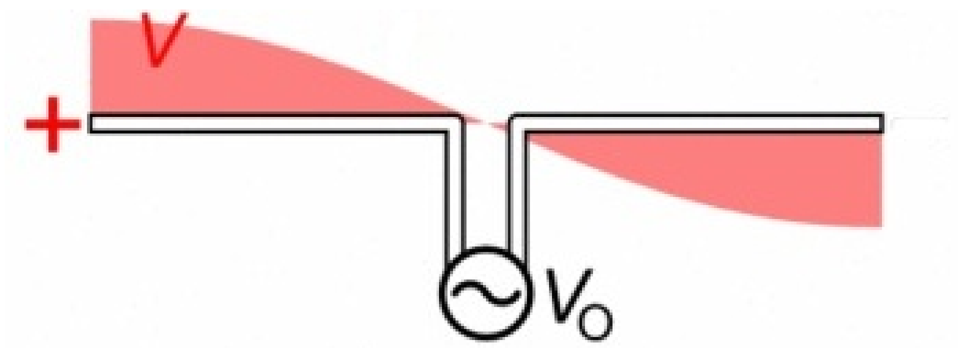




Anténa ?

$$E_C = \frac{1}{2}CU^2 \qquad E_L = \frac{1}{2}LI^2$$



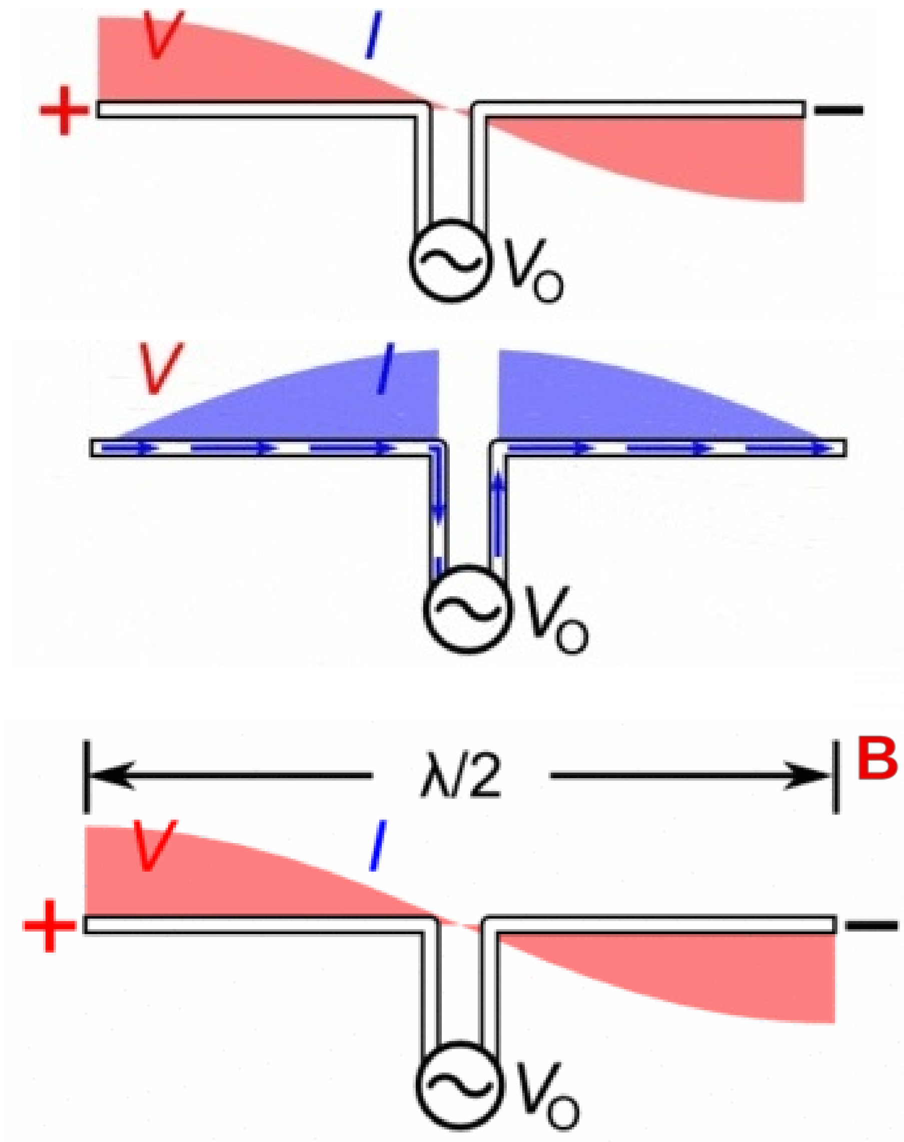


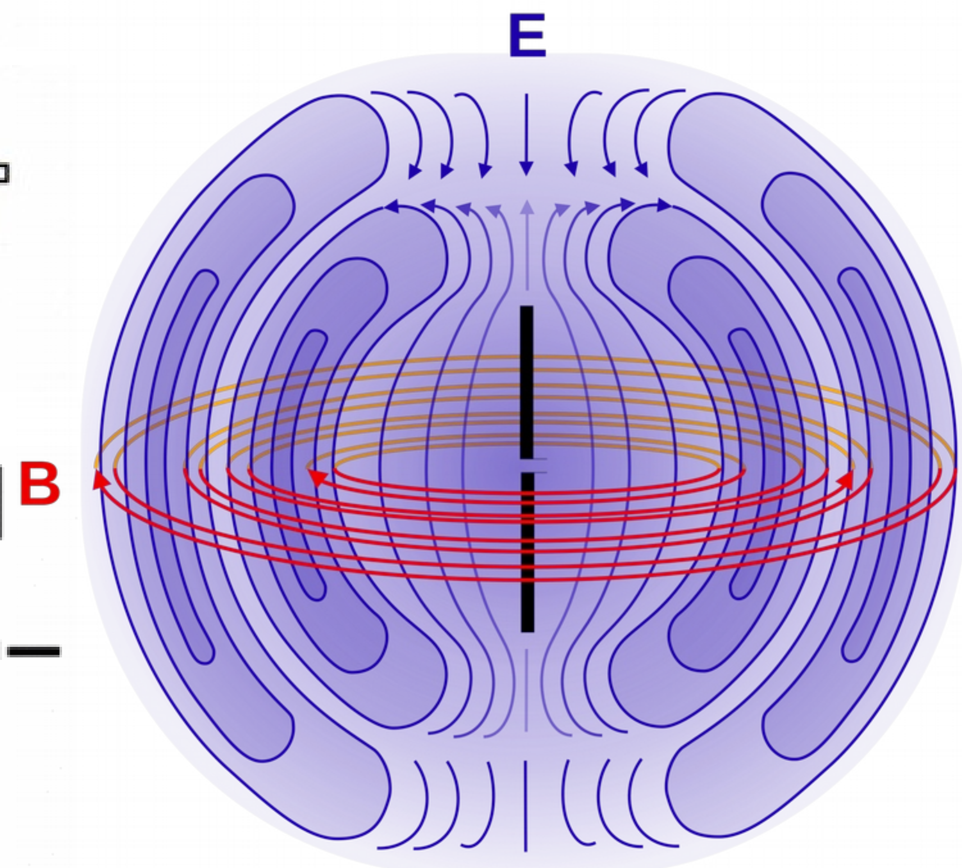
V Hetzově anténě již nejsou náboje rozloženy podle pravidel elektrostatiky a proudy nejsou stacionární!

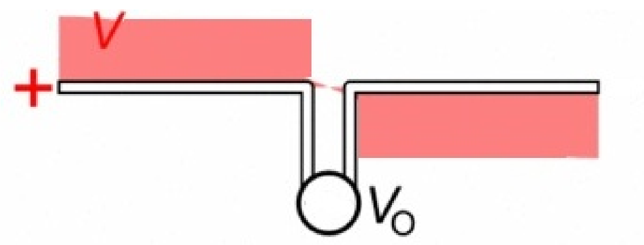
Na rozdíl od kondenzátoru a cívky tak nad nimi (a jejich energií) ztrácíme kontrolu – ta může odletět v podobě vln pryč.

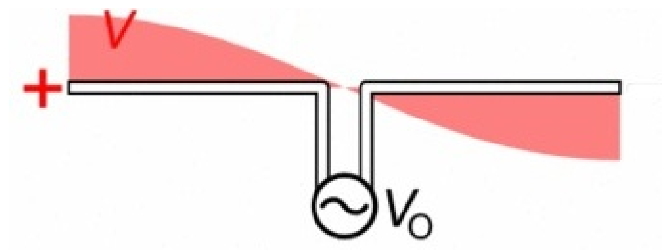
Pozor – to červené není napětí, ale náboj

Pozor – to červené není napětí, ale náboj









$$\mathbf{B}(\mathbf{r},t) = -\frac{\mu_0}{4\pi}\hat{\mathbf{r}} \times \left\{ \frac{\dot{\mathbf{p}}_{\mathrm{ret}}}{r^2} + \frac{\ddot{\mathbf{p}}_{\mathrm{ret}}}{cr} \right\}$$

$$\mathbf{E}(\mathbf{r},t) = \frac{1}{4\pi\epsilon_0}\left\{ \frac{3\hat{\mathbf{r}}(\hat{\mathbf{r}}\cdot\mathbf{p}_{\mathrm{ret}}) - \mathbf{p}_{\mathrm{ret}}}{r^3} + \frac{3\hat{\mathbf{r}}(\hat{\mathbf{r}}\cdot\dot{\mathbf{p}}_{\mathrm{ret}}) - \dot{\mathbf{p}}_{\mathrm{ret}}}{cr^2} + \frac{\hat{\mathbf{r}}(\hat{\mathbf{r}}\cdot\ddot{\mathbf{p}}_{\mathrm{ret}}) - \ddot{\mathbf{p}}_{\mathrm{ret}}}{c^2 r} \right\}$$

$$P_{\mathrm{E1}}(t) = \frac{1}{4\pi\epsilon_0}\frac{2|\ddot{\mathbf{p}}_{\mathrm{ret}}|^2}{3c^3}$$

$$P_{\mathrm{M1}}(t) = \frac{\mu_0}{4\pi}\frac{2|\ddot{\mathbf{m}}_{\mathrm{ret}}|^2}{3c^3},$$

Vyzářený výkon lze dobře odhadnout

* p …… součin náboje a délky
* m …… součin proudu a plochy

.. …… $(2\pi f)^2$

* ret …… vlnám to chvíli trvá

Friisova rovnice

$$P_R = A_R \mathcal{P}_T = \frac{P_T G_T A_R}{4\pi r^2}$$

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

$$G = \frac{A_{eff}}{\lambda^2/4\pi} = \frac{4\pi A_{phys} e_a}{\lambda^2}$$

Example 15.6.1: A geosynchronous satellite is transmitting a TV signal to an earth-based station at a distance of 40,000 km. Assume that the dish antennas of the satellite and the earth station have diameters of 0.5 m and 5 m, and aperture efficiencies of 60%. If the satellite's transmitter power is 6 W and the downlink frequency 4 GHz, calculate the antenna gains in dB and the amount of received power.

Solution: The wavelength at 4 GHz is $\lambda = 7.5$ cm. The antenna gains are calculated by:

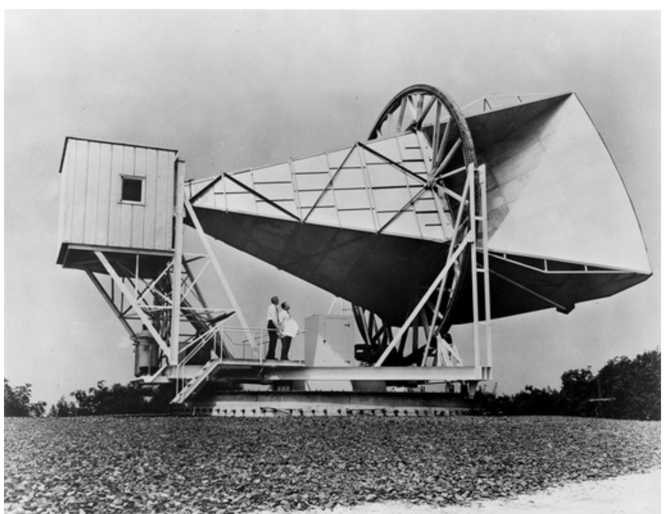
$$G = e_a \left(\frac{\pi d}{\lambda} \right)^2 \quad \Rightarrow \quad G_{\text{sat}} = 263.2 = 24 \text{ dB}, \quad G_{\text{earth}} = 26320 = 44 \text{ dB}$$

Because the ratio of the earth and satellite antenna diameters is 10, the corresponding gains will differ by a ratio of 100, or 20 dB. The satellite's transmitter power is in dB, $P_T = 10\log_{10}(6) = 8$ dBW, and the free-space loss and gain:

$$L_f = \left(\frac{4\pi r}{\lambda} \right)^2 = 4 \times 10^{19} \quad \Rightarrow \quad L_f = 196 \text{ dB}, \quad G_f = -196 \text{ dB}$$

It follows that the received power will be in dB:

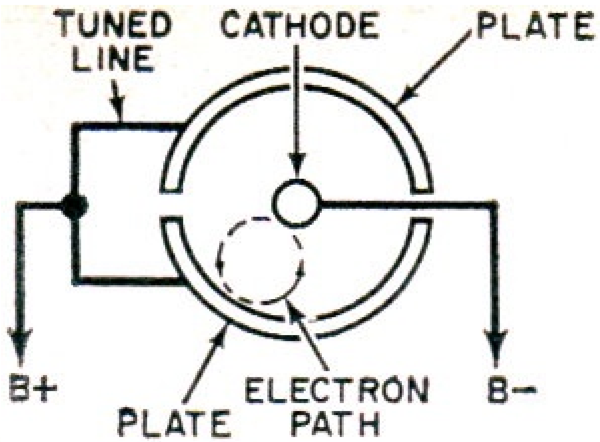
$$P_R = P_T + G_T - L_f + G_R = 8 + 24 - 196 + 44 = -120 \text{ dBW} \quad \Rightarrow \quad P_R = 10^{-12} \text{ W}$$

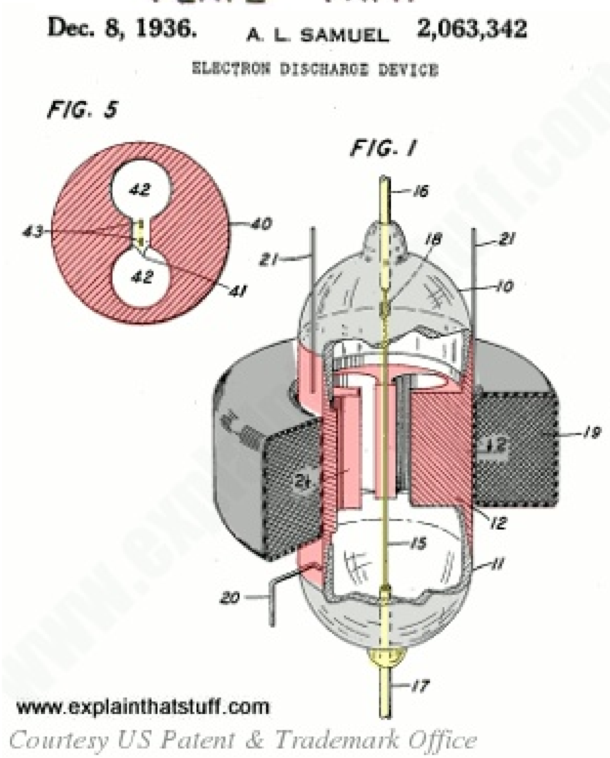


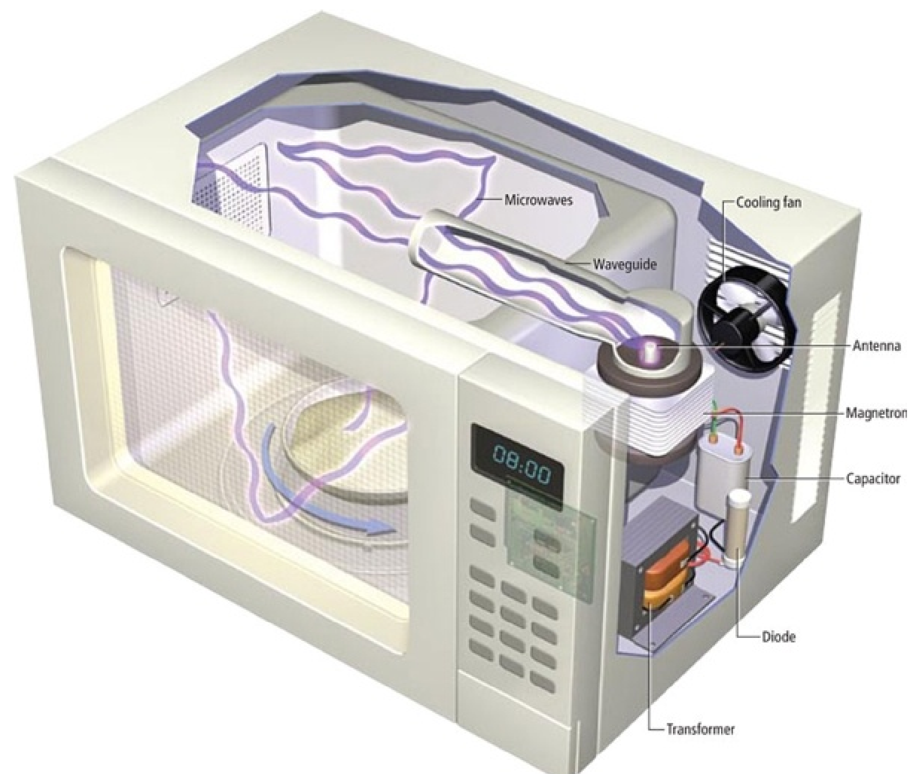
Ukázkový problém z učebnice
S.J. Orfanidis: *Electromagnetic Waves and Antennas*

Výkon !

Elektromagnetické vlny nejsou jen ony slabé vlnky v éteru ….

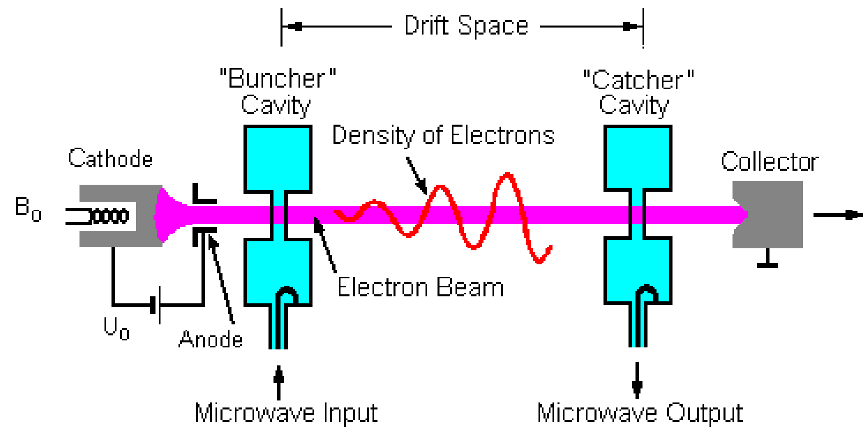


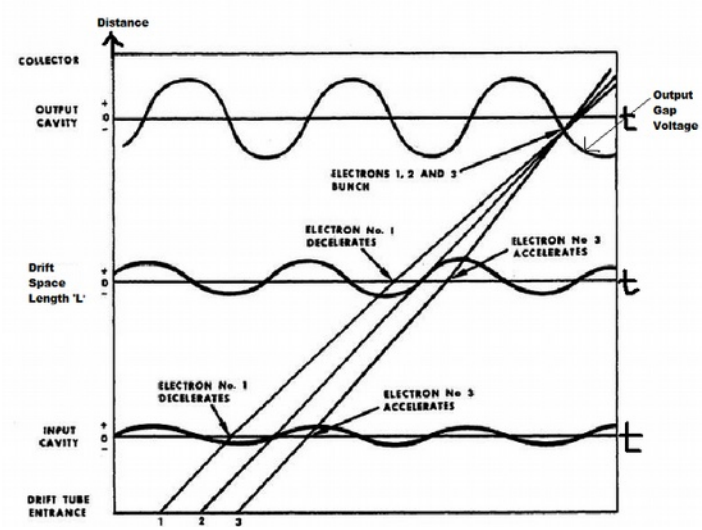




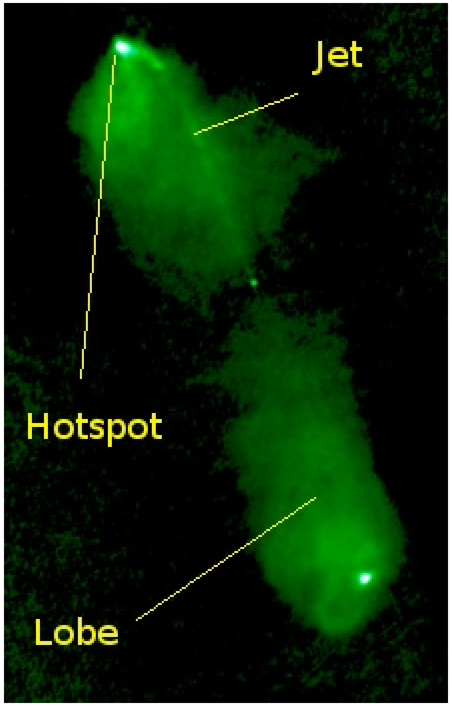
Výkon !

Fig. 19 The SLAC 11.4 GHz, 75-MW PPM klystron





Výkon !



Rádiové rekordy

Rádiové galaxie:

10^{39} W v pásmu 10 MHz – 100 Ghz

Pulsary

10^{24} W v pásmu 200 – 600 MHz

Transatlantické telefonování

1928: Bell Labs

výzkum atmosférických poruch a vlastností ionosféry

krátké vlny (15 MHz, anténa rozměr 30 m)

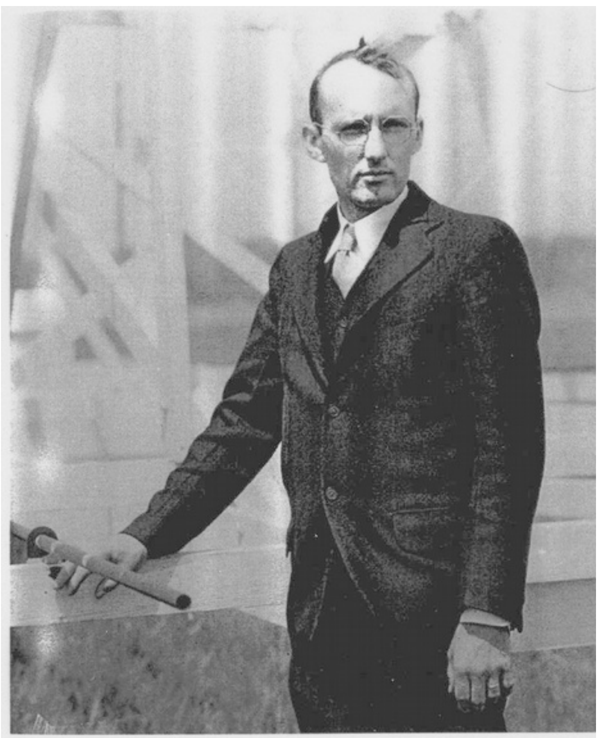
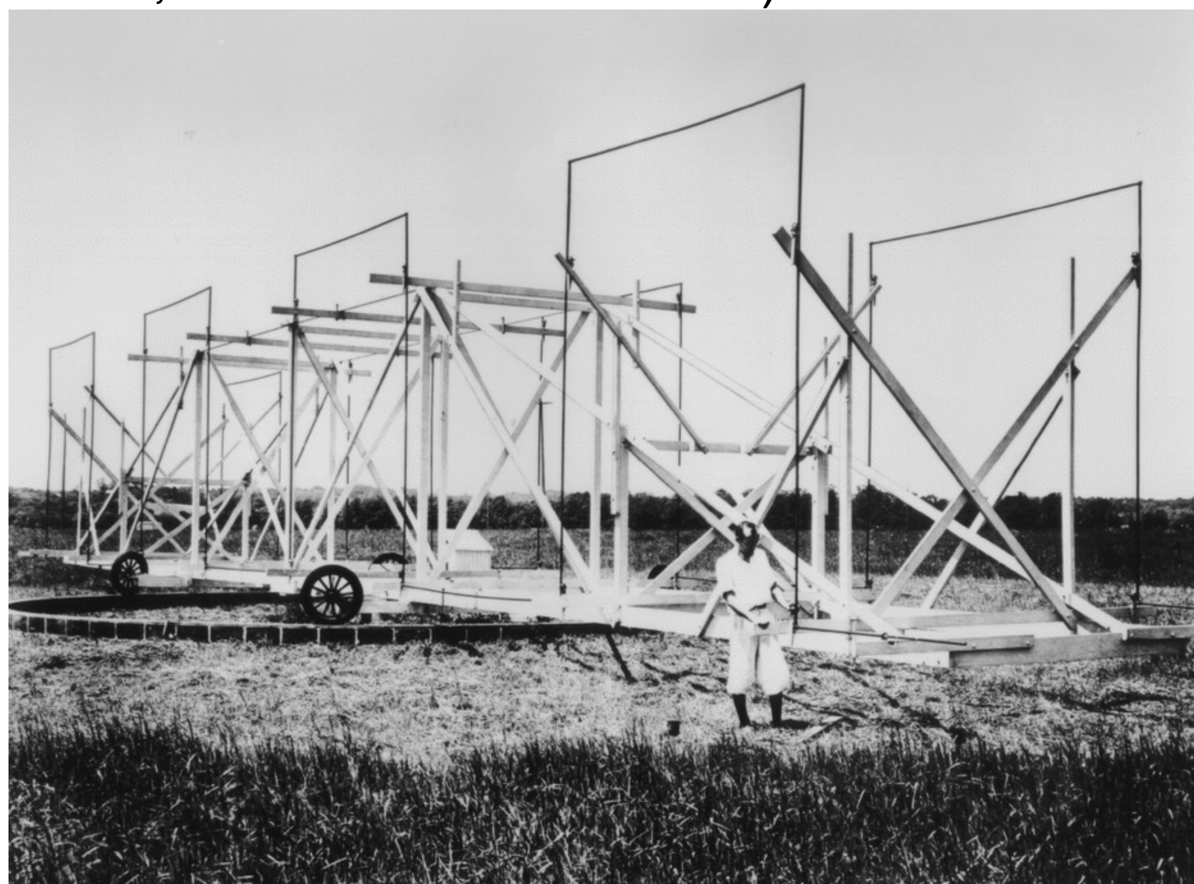


Fig. 1—Karl Guthe Jansky, about 1933.



Karl Jansky

- Bouřky
- Bouřky
- a Neznámý šum

NEW RADIO WAVES TRACED TO CENTRE OF THE MILKY WAY

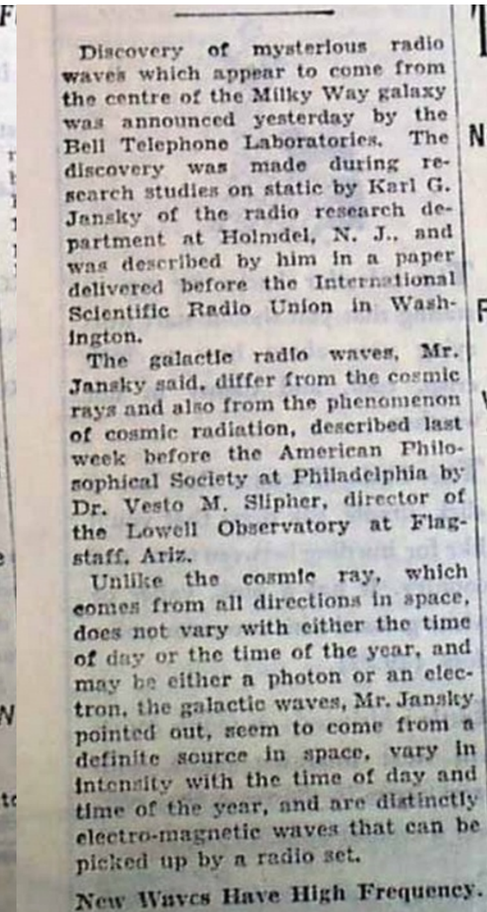
Mysterious Static, Reported by K. G. Jansky, Held to Differ From Cosmic Ray.

DIRECTION IS UNCHANGING

Recorded and Tested for More Than Year to Identify It as From Earth's Galaxy.

ITS INTENSITY IS LOW

Only Delicate Receiver Is Able to Register—No Evidence of Interstellar Signaling.



Discovery of mysterious radio waves which appear to come from the centre of the Milky Way galaxy was announced yesterday by the Bell Telephone Laboratories. The discovery was made during research studies on static by Karl G. Jansky of the radio research department at Holmdel, N. J., and was described by him in a paper delivered before the International Scientific Radio Union in Washington.

The galactic radio waves, Mr. Jansky said, differ from the cosmic rays and also from the phenomenon of cosmic radiation, described last week before the American Philosophical Society at Philadelphia by Dr. Vesto M. Slipher, director of the Lowell Observatory at Flagstaff, Ariz.

Unlike the cosmic ray, which comes from all directions in space, does not vary with either the time of day or the time of the year, and may be either a photon or an electron, the galactic waves, Mr. Jansky pointed out, seem to come from a definite source in space, vary in intensity with the time of day and time of the year, and are distinctly electro-magnetic waves that can be picked up by a radio set.

New Waves Have High Frequency.

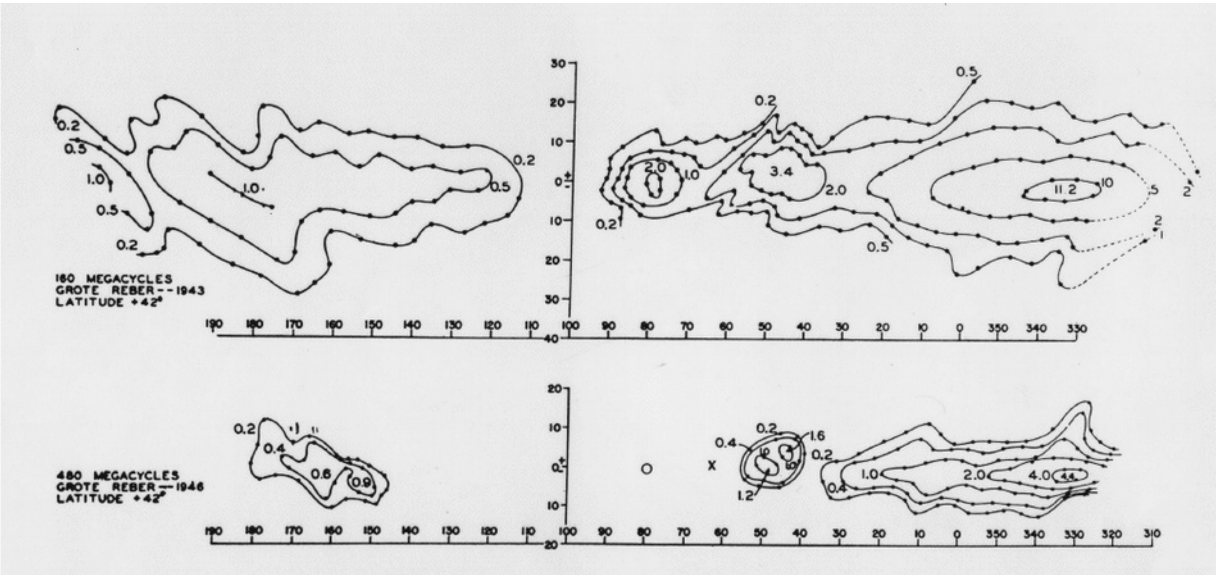
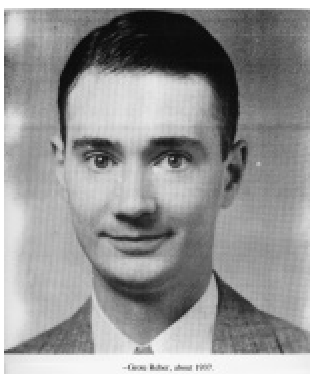
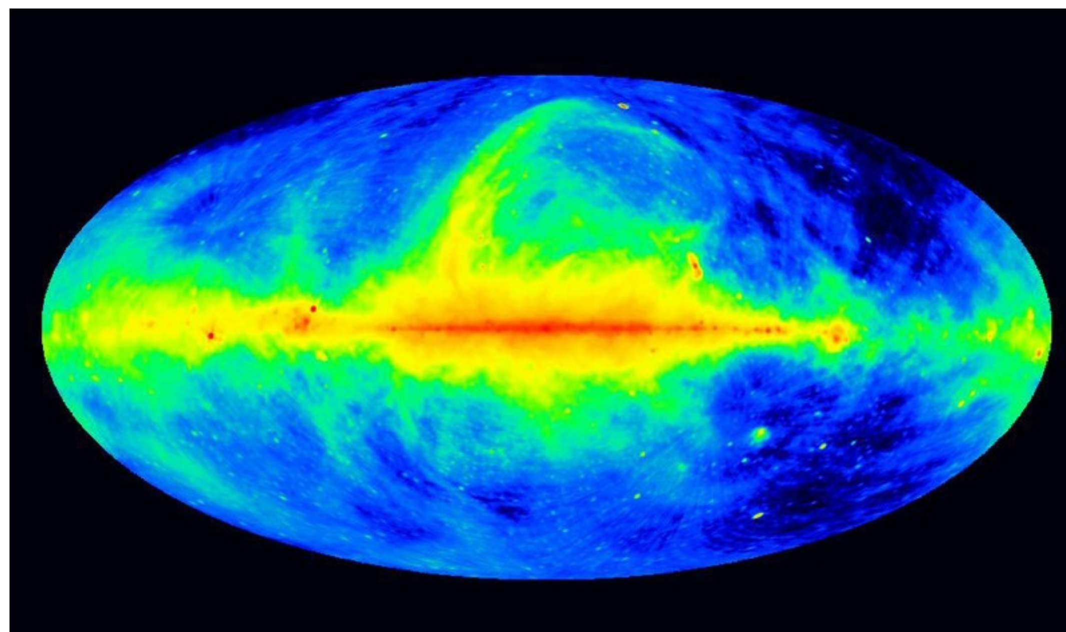


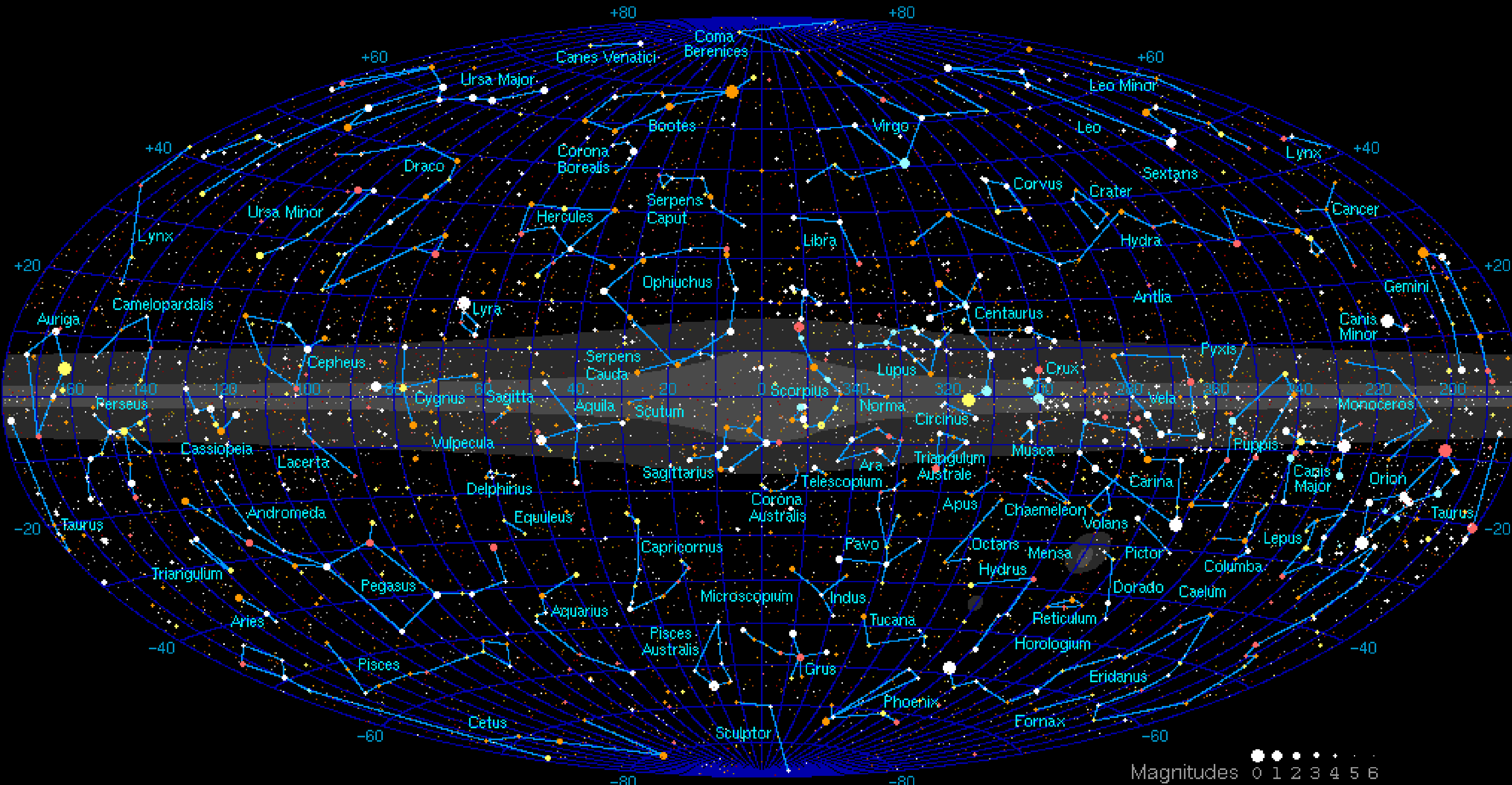
FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.



Grote Reber

408MHz
Haslam et al. 1982




+80
+80
+60
+60
+40
+40
+20
+20
-20
-20
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-60
-60
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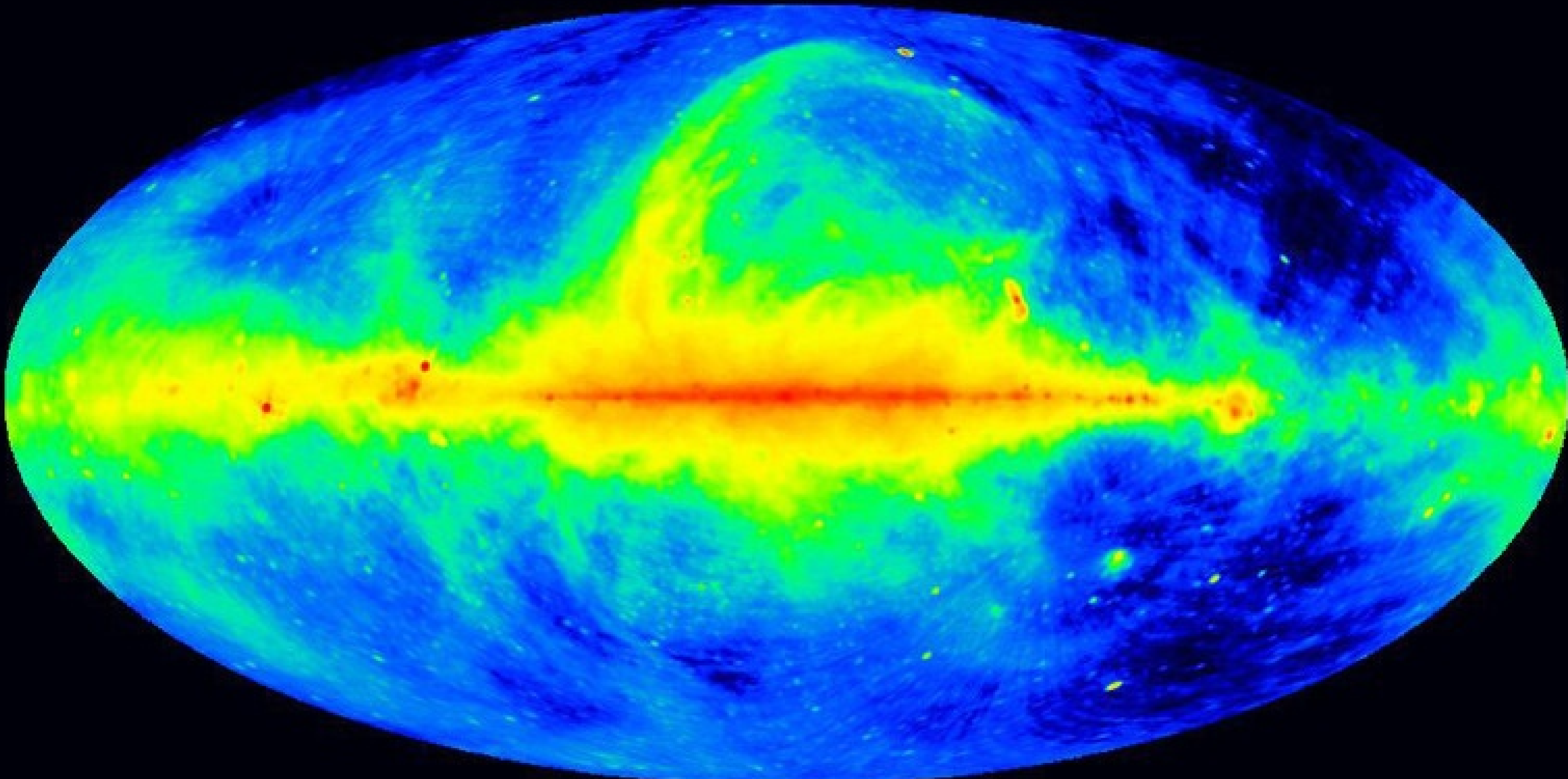
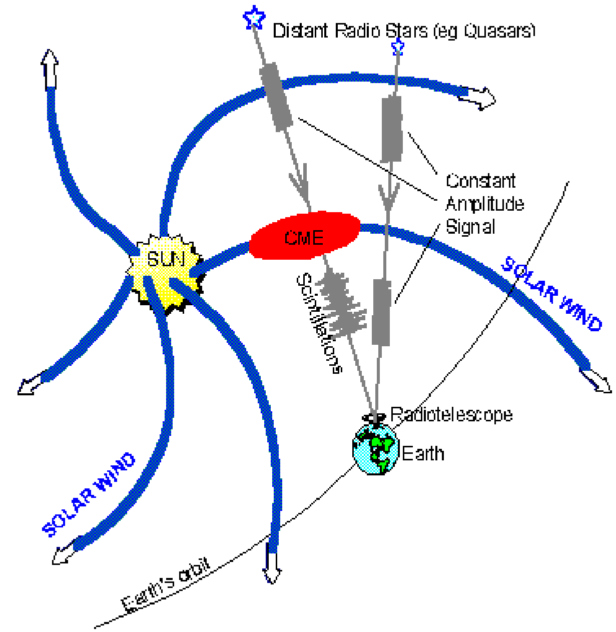
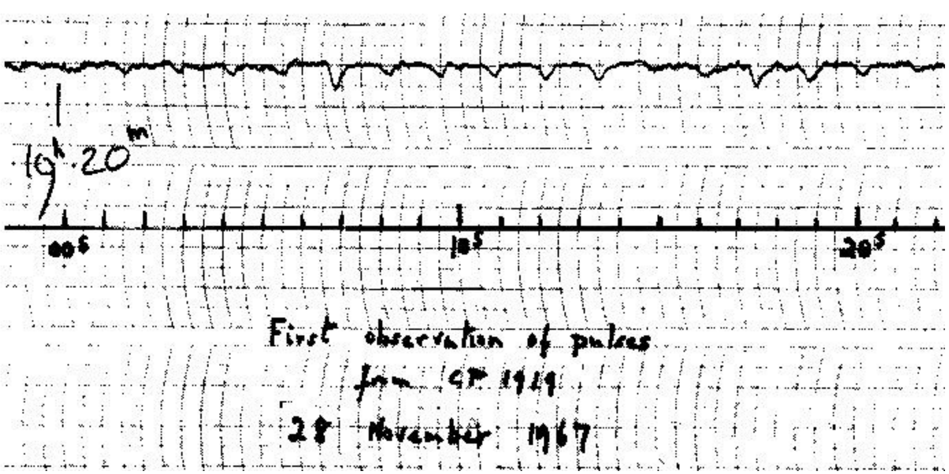
-80
160
140
120
100
80
60
40
20
0
340
320
300
280
260
240
220
200
Coma Berenices
Canes Venatici
Ursa Major
Bootes
Corona Borealis
Draco
Virgo
Leo Minor
Leo
Lynx
Sextans
Corvus
Crater
Cancer
Serpens Caput
Hercules
Ursa Minor
Lynx
Libra
Hydra
Ophiuchus
Gemini
Antlia
Camelopardalis
Auriga
Lyra
Centaurus
Canis Minor
Cepheus
Serpens Cauda
Pyxis
Lupus
Crux
Perseus
Cygnus
Sagitta
Aquila
Scutum
Scorpius
Norma
Circinus
Vela
Monoceros
Vulpecula
Cassiopeia
Lacerta
Sagittarius
Ara
Triangulum Australe
Musca
Puppis
Canis Major
Orion
Telescopium
Carina
Delphinus
Corona Australis
Andromeda
Equuleus
Apus
Chaemeleon
Volans
Taurus
Taurus
Lepus
Capricornus
Pavo
Octans
Mensa
Pictor
Triangulum
Columba
Pegasus
Hydrus
Dorado
Caelum
Microscopium
Indus
Aquarius
Aries
Tucana
Reticulum
Pisces Australis
Horologium
Pisces
Grus
Eridanus
Phoenix
Cetus
Fornax
Sculptor
Magnitudes 0 1 2 3 4 5 6

r powell

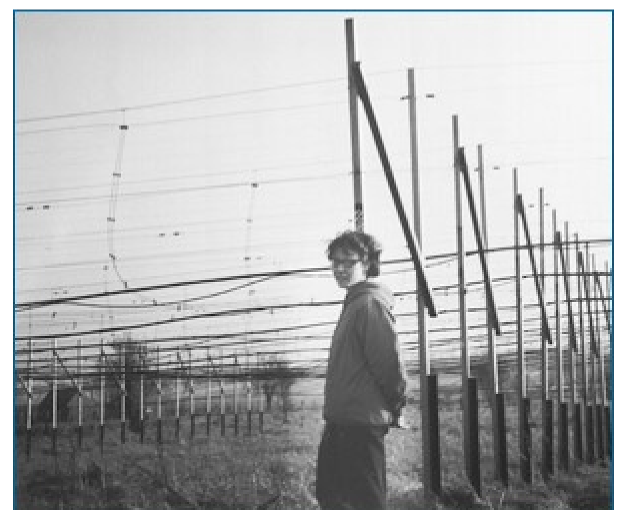


Jaké je dnes počasí u Venuše?

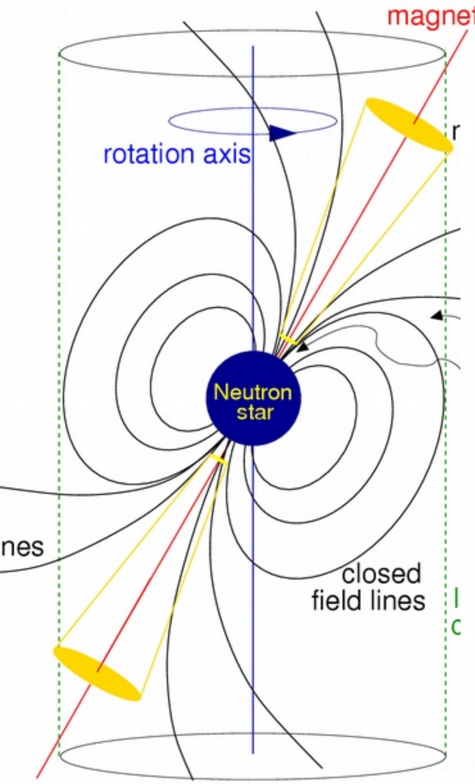




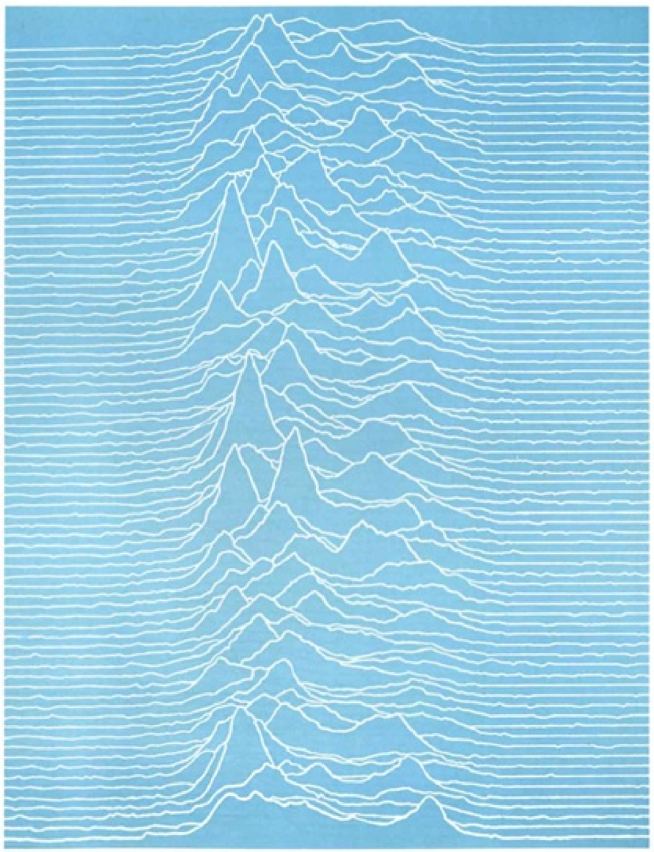
Jocelyn Bell



Pulsary

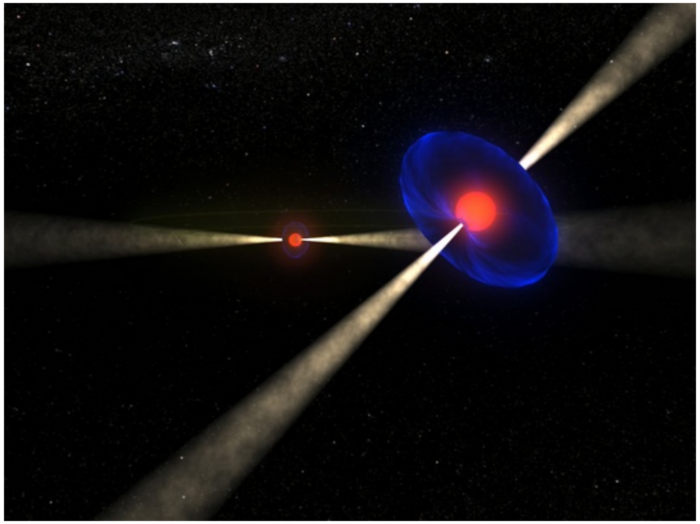


Handbook of Pulsar Astronomy (Lorimer and Kramer, 2004)



EIGHTY SUCCESSIVE PERIODS of the first pulsar observed, CP1919 (Cambridge pulsar at 19 hours 19 minutes right ascension), are stacked on top of one another using the average period of 1.33730 seconds in this computer-generated illustration produced at the Arecibo Radio Observatory in Puerto Rico. Although the leading edges of the radio pulses occur within a few thousandths of a second of the predicted times, the shape of the pulses is quite irregular. Some of this irregularity in radio reception is caused by the effects of transmission through the interstellar medium. The average pulse width is less than 50 thousandths of a second.

53



na víc už nám nezbyl čas ...