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2	March 7–10	**3**	Electrostatics. Coulomb's law, scalar potential, electric dipole, permittivity, conductors and insulators, capacitance, electrostatic energy and forces.
3	March 14–17	**4 and 5**	Static electric currents, Ohm's law, conductivity. Magnetostatics, Biot-Savart's law, vector potential, permeability, magnetic dipole, inductance.
4	March 21–24	**6**	Faraday's law, Maxwell equations for dynamic electromagnetic fields. Complex representation of time-harmonic fields.
5	March 28 – 31	**7**	Plane waves in lossless and lossy media. Attenuation of waves, Wave reflection from planar interfaces. Brewster angle.
6	April 4–7	**(8,9) 10**	Electromagnetic radiation. Fields generated by a Hertzian dipole.

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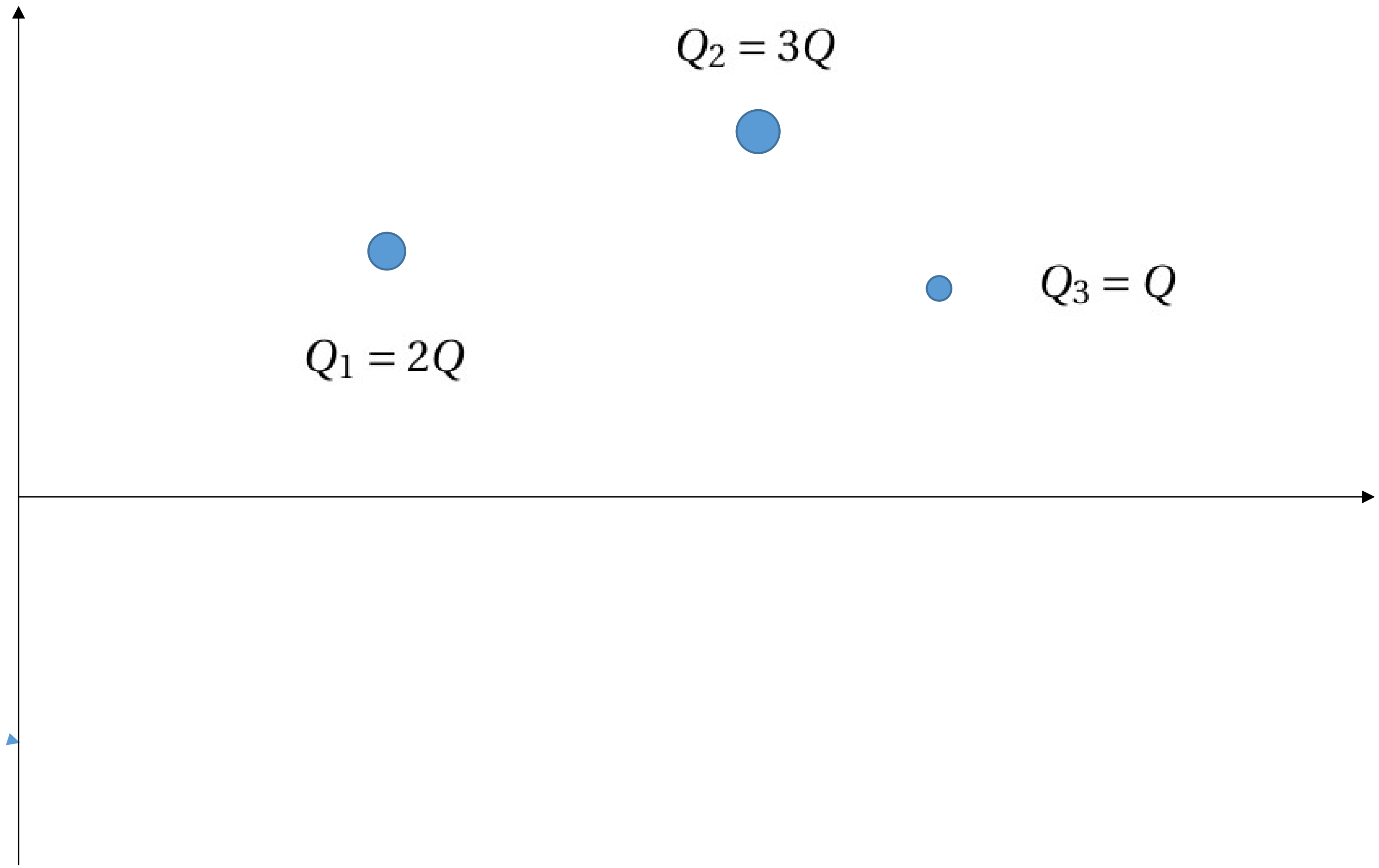
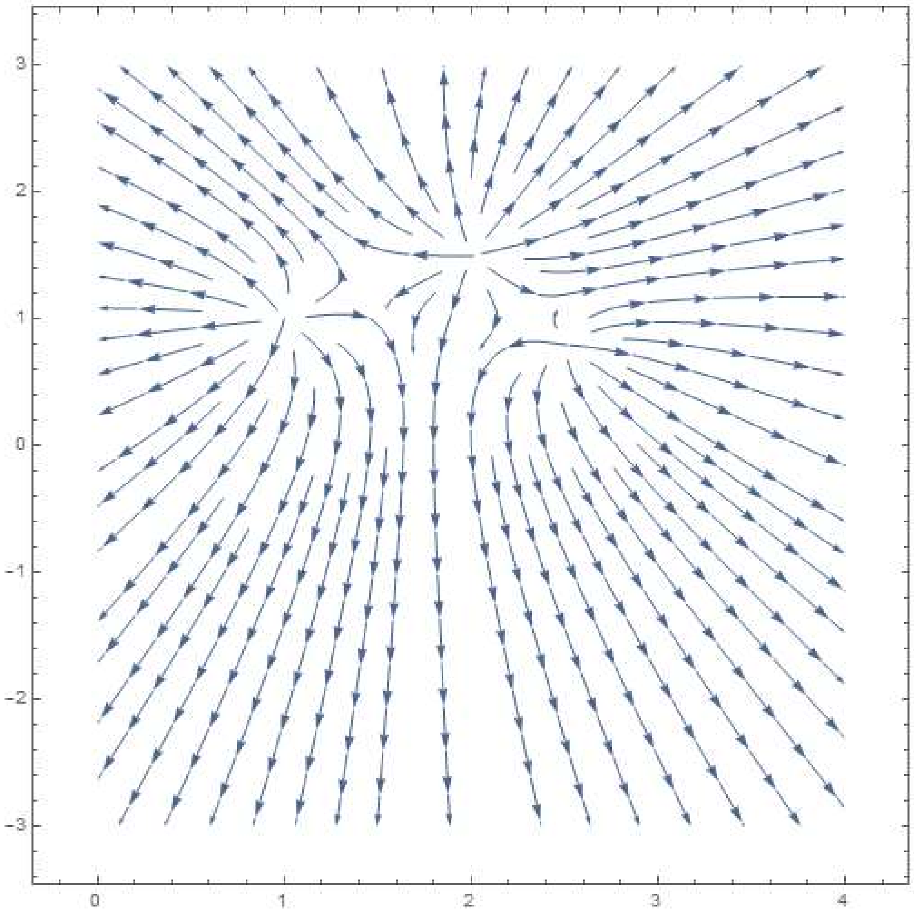
Image principle (mirror image)

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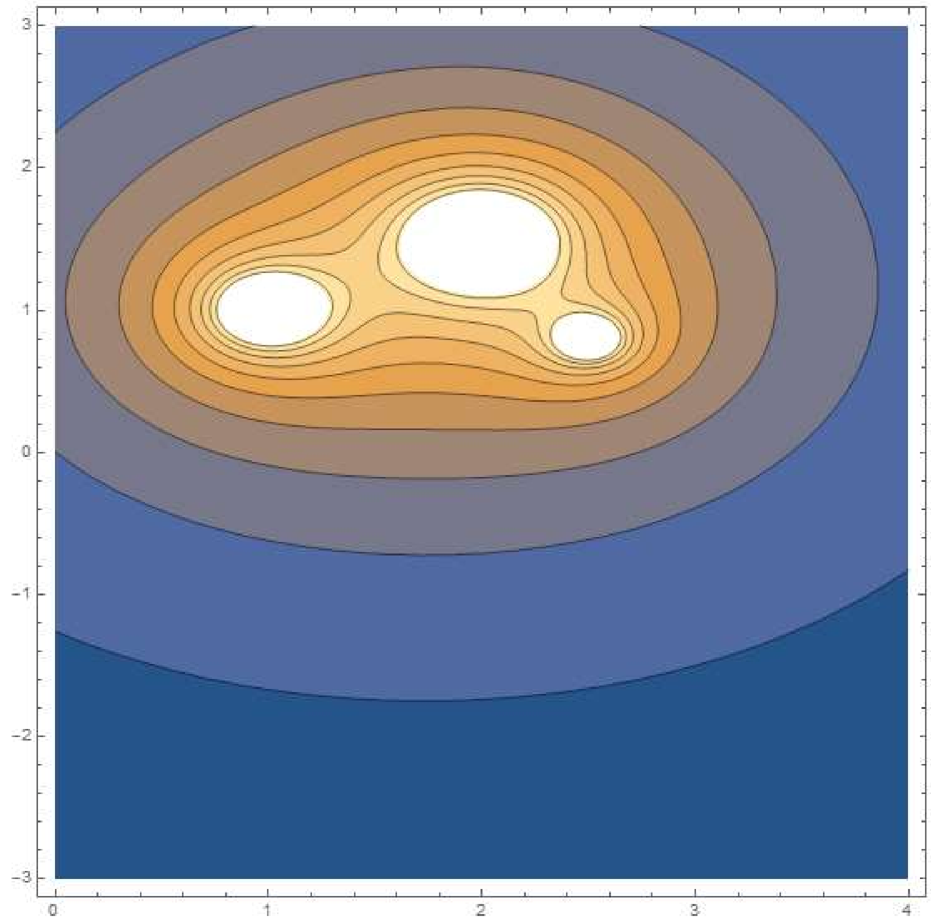
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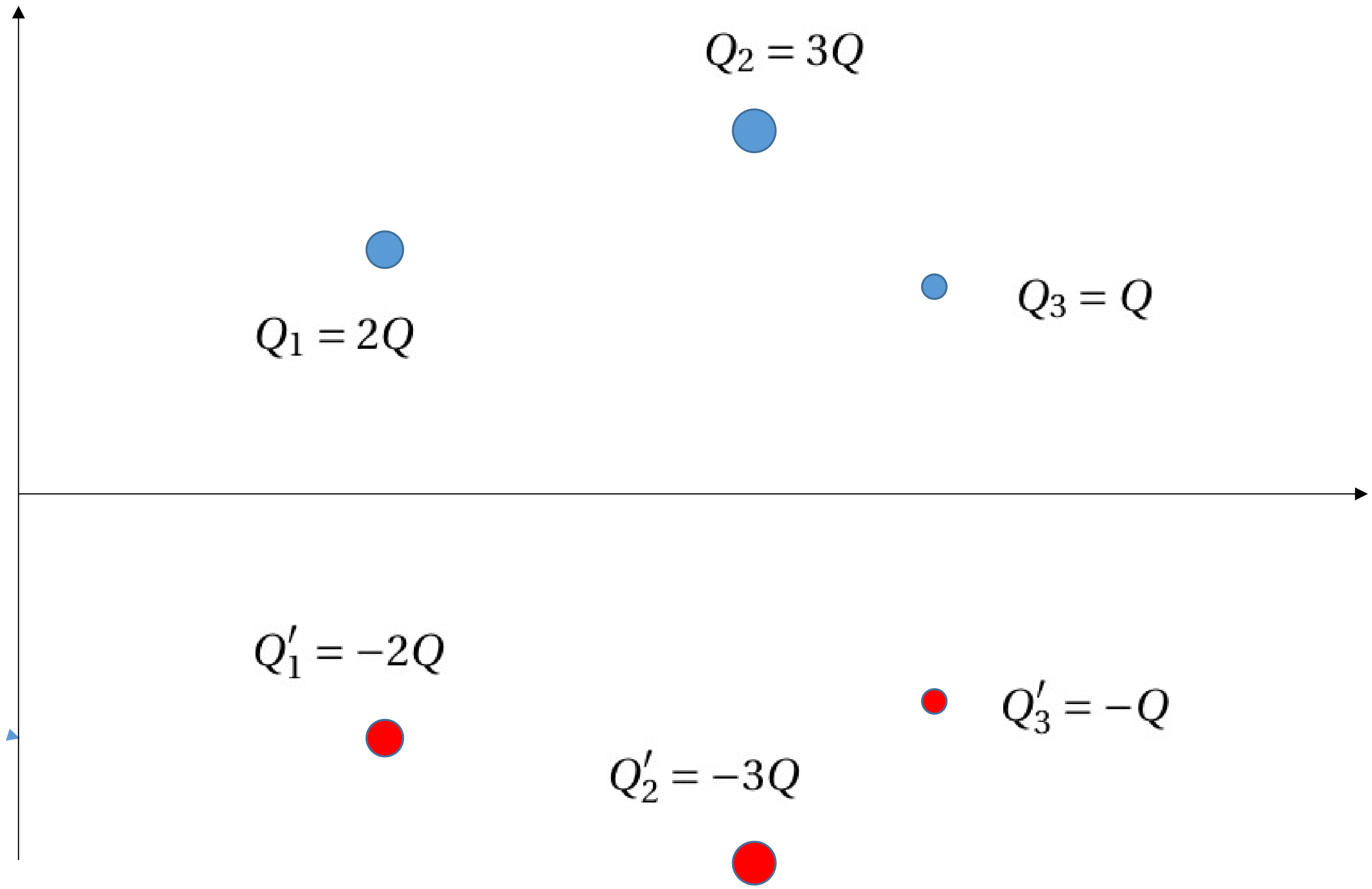
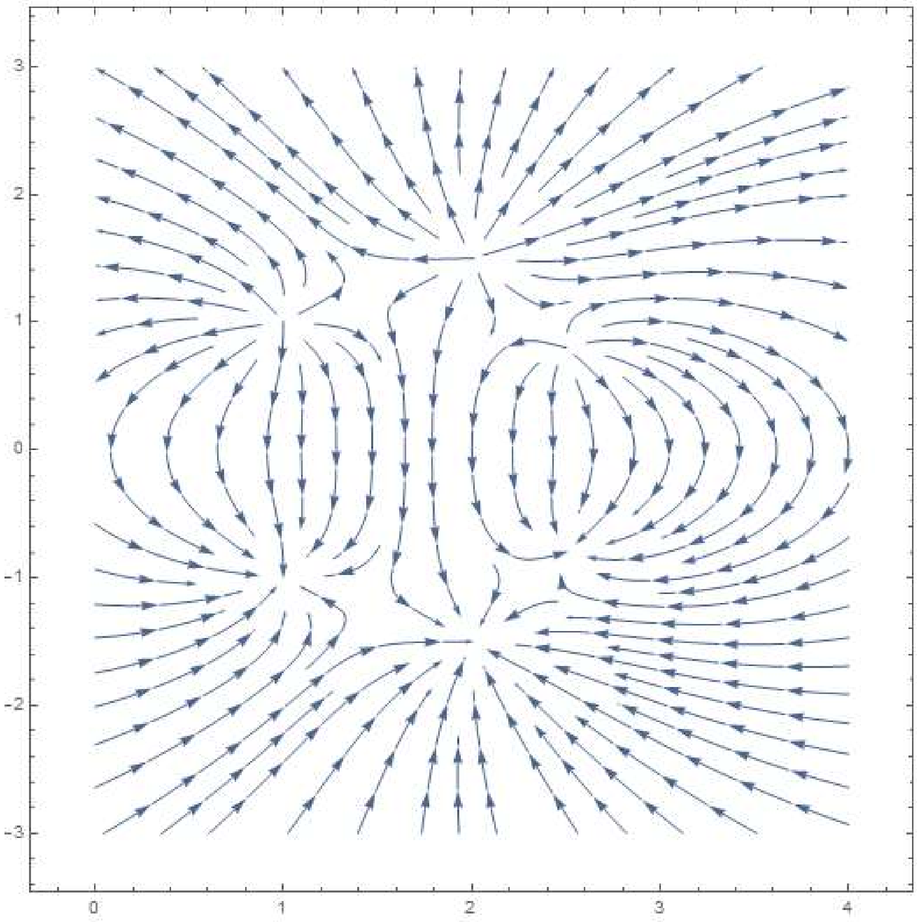
Image principle (mirror image)





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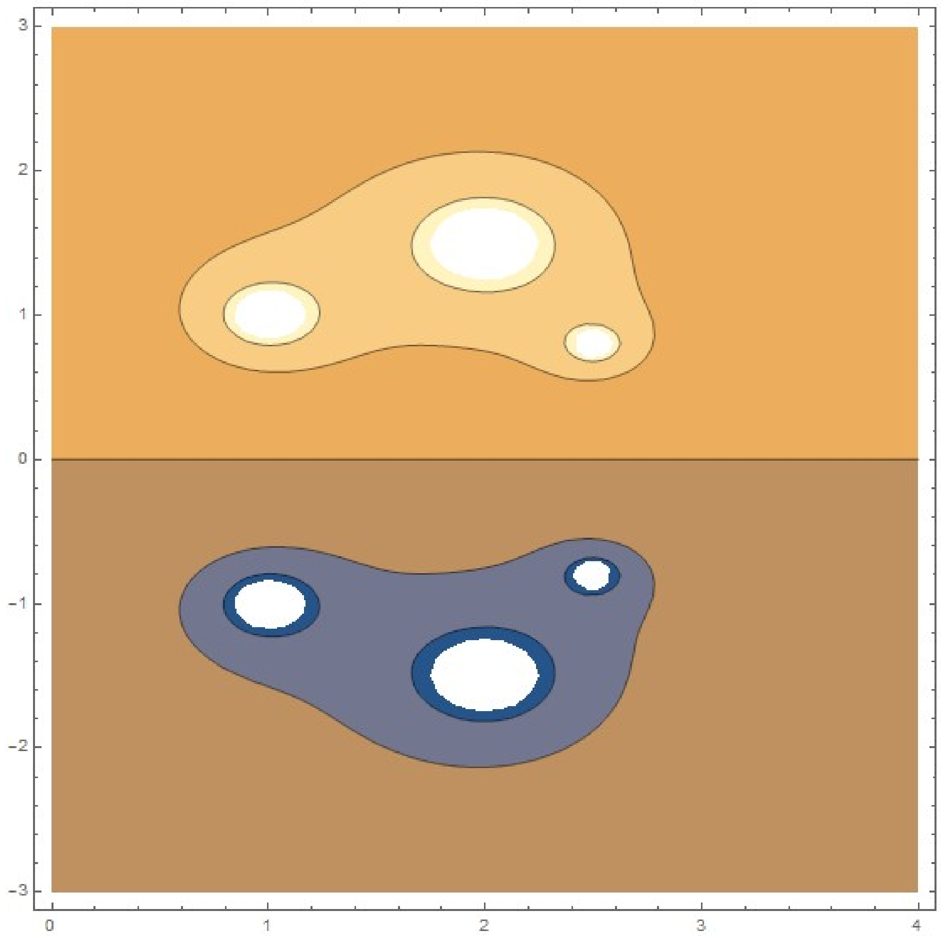

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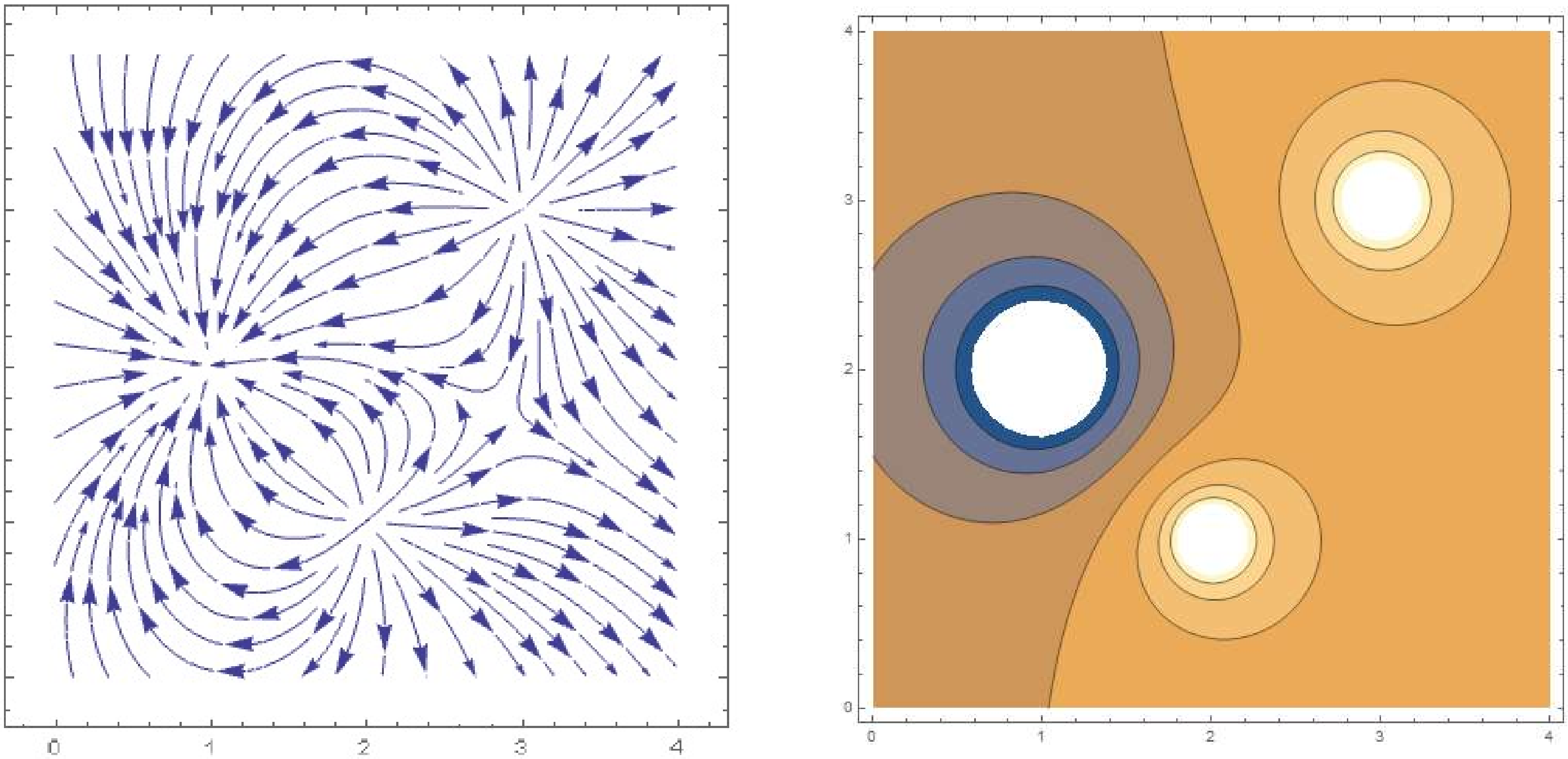
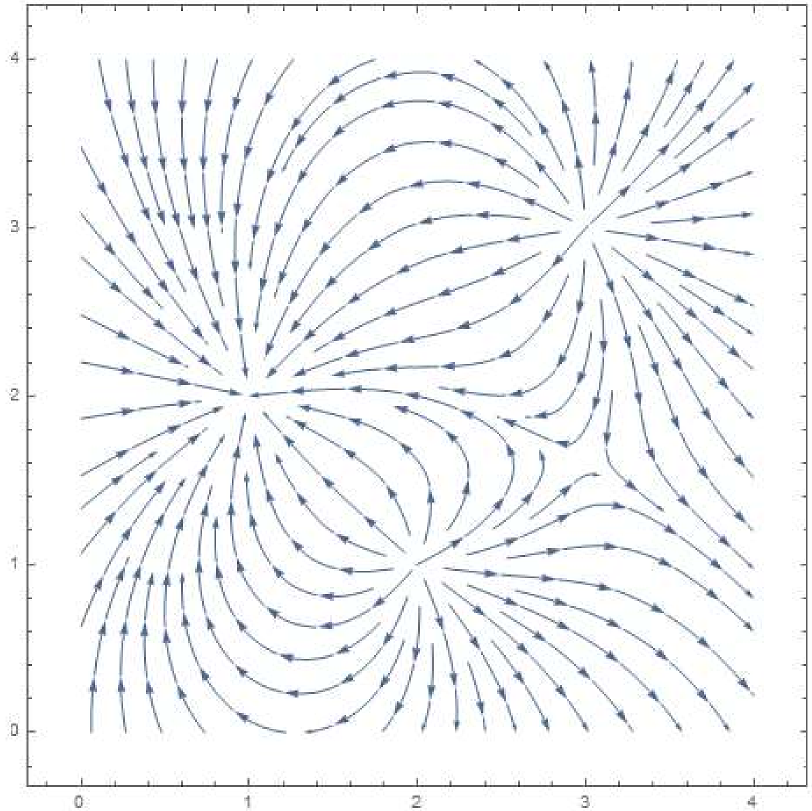
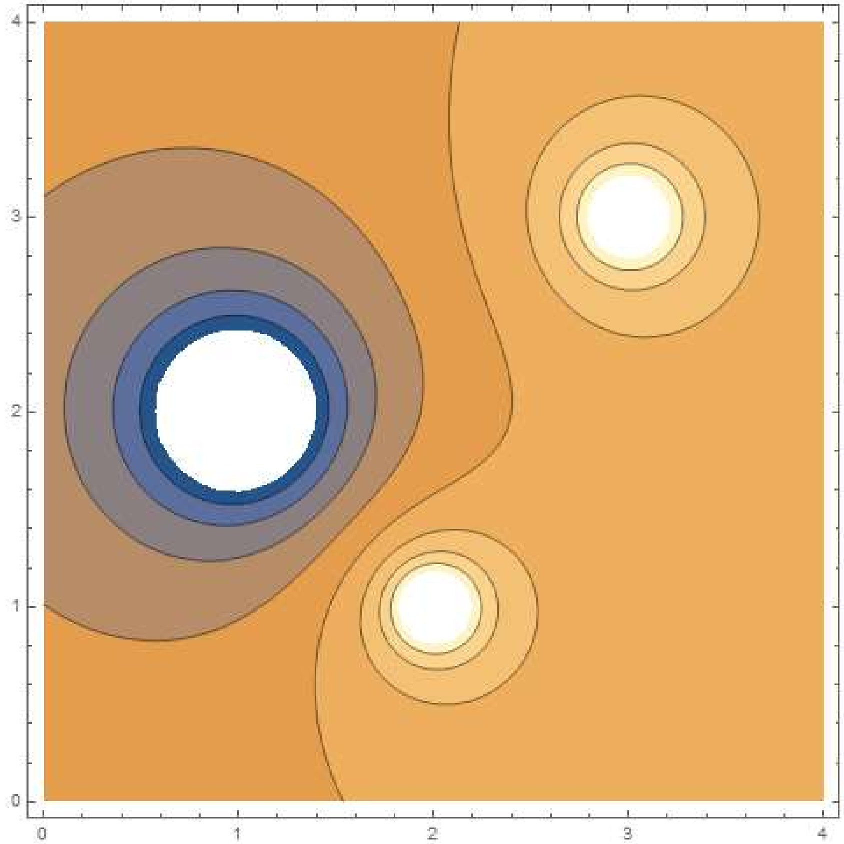
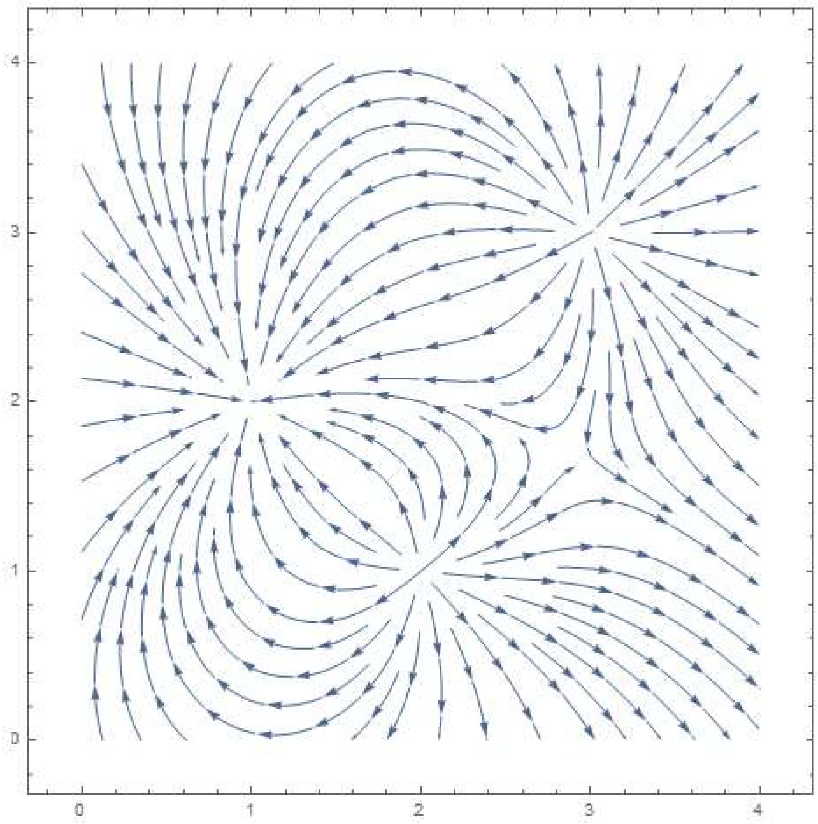


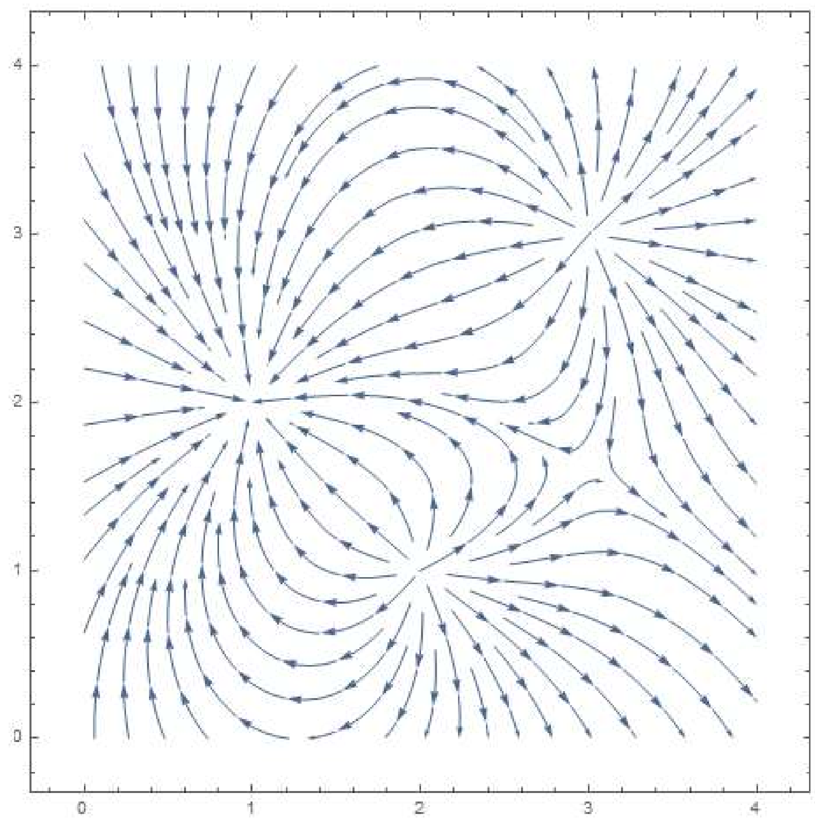
Three point charges: **+1[C]** & **+1[C]** & **-2[C]**



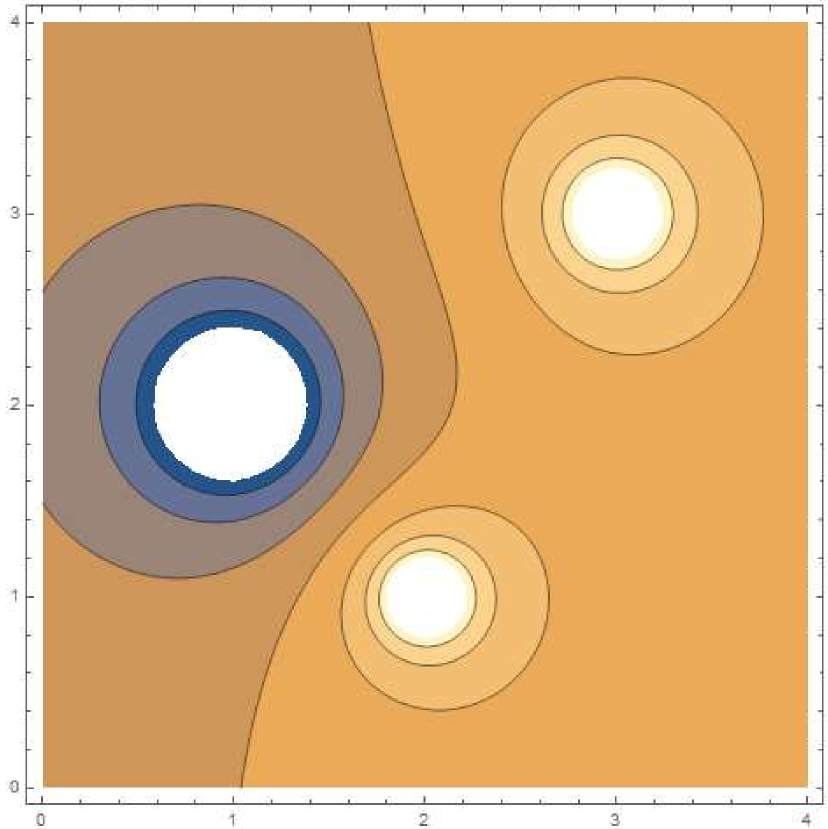


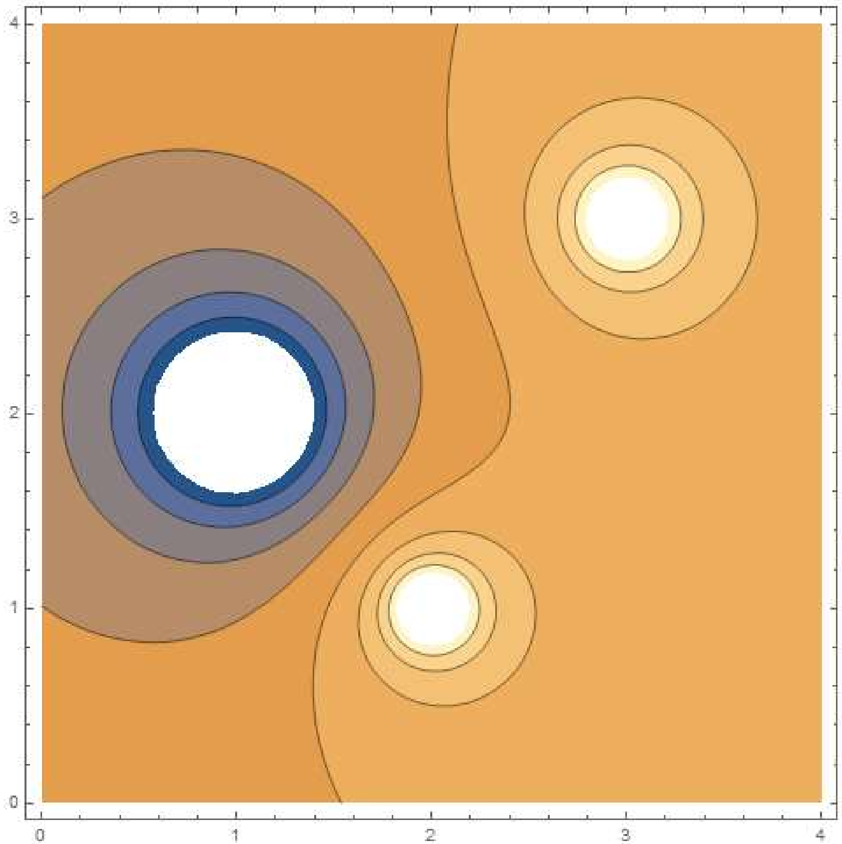
Three point charges: **+1[C]** & **+1[C]** & **-2,5[C]**





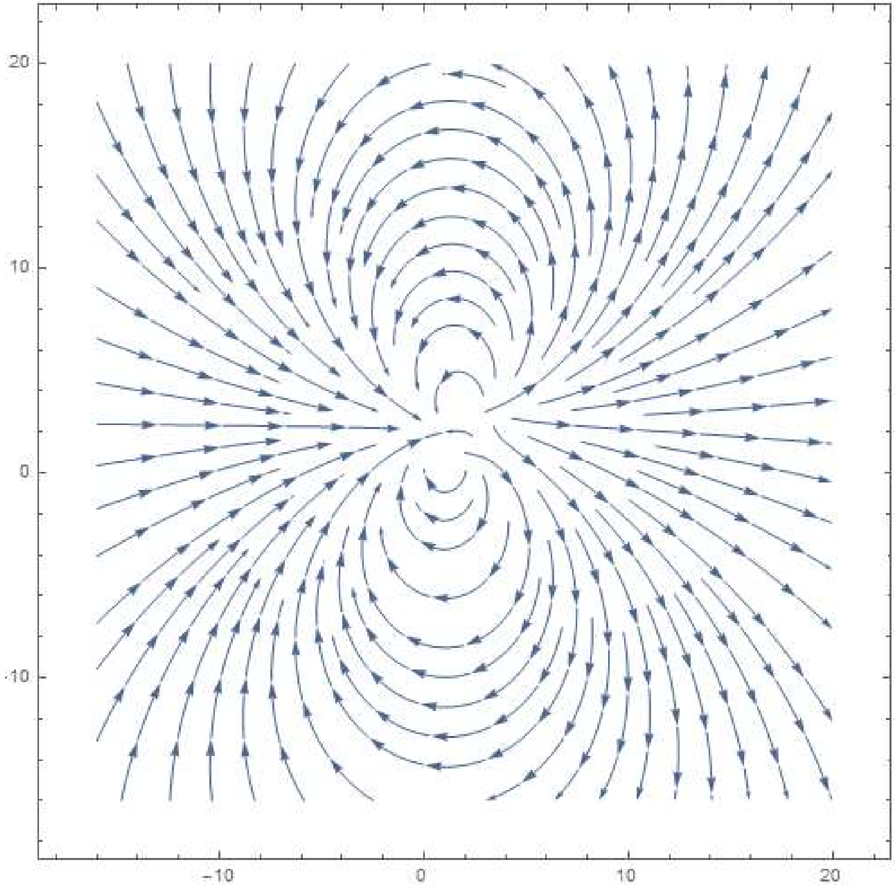
Any difference?

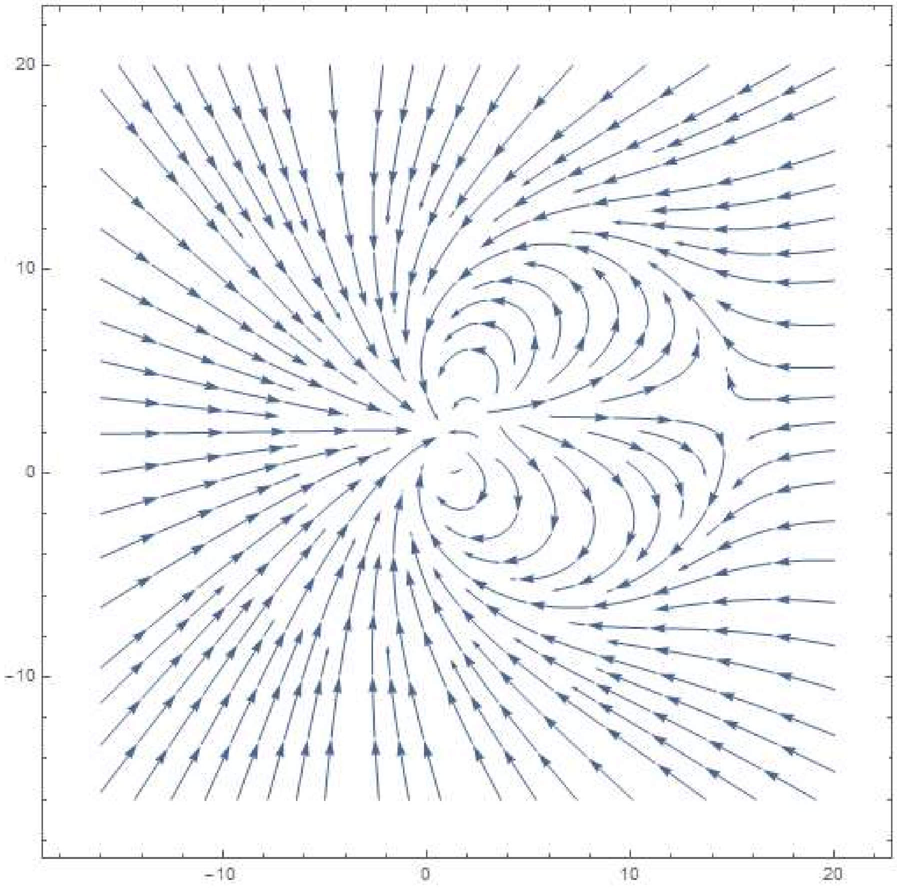




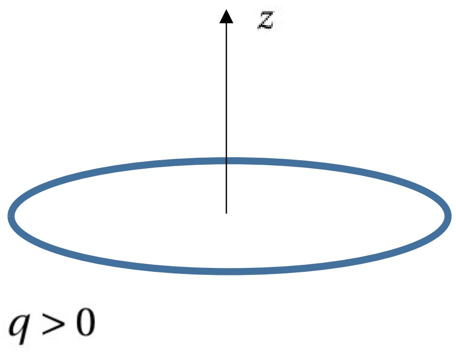
Any difference?

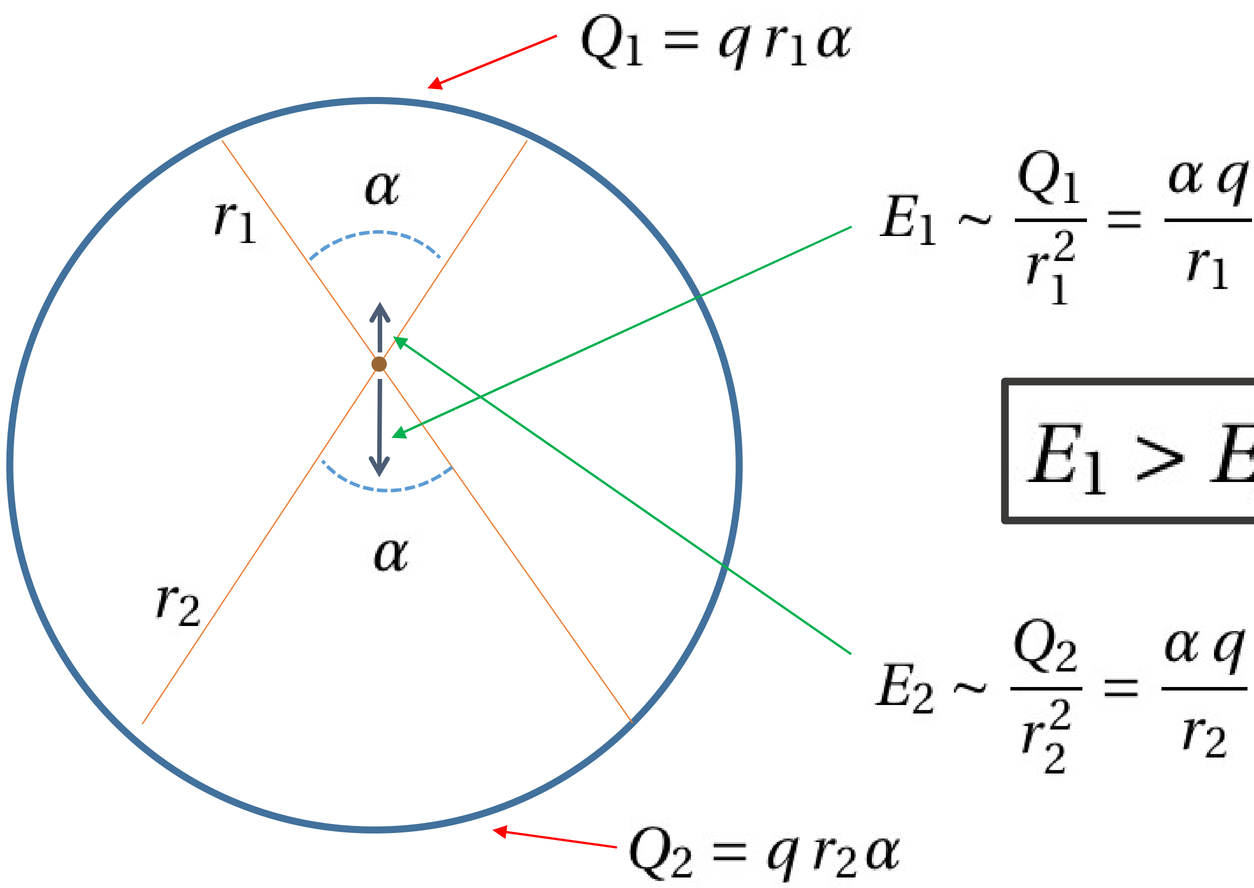
How about a more distant view?





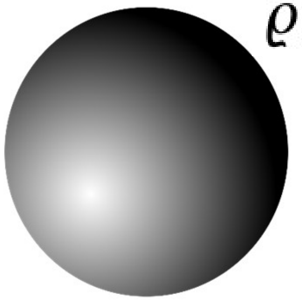
Circular line charge ($q > 0$: C/m)



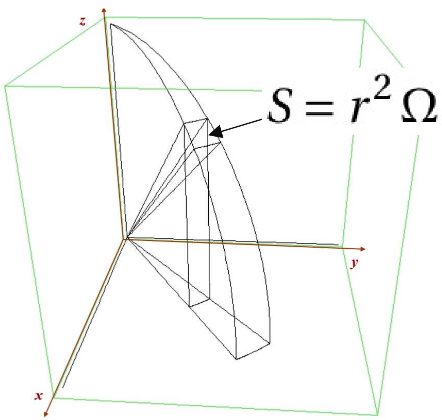


$$\boxed{E_1 > E_2}$$

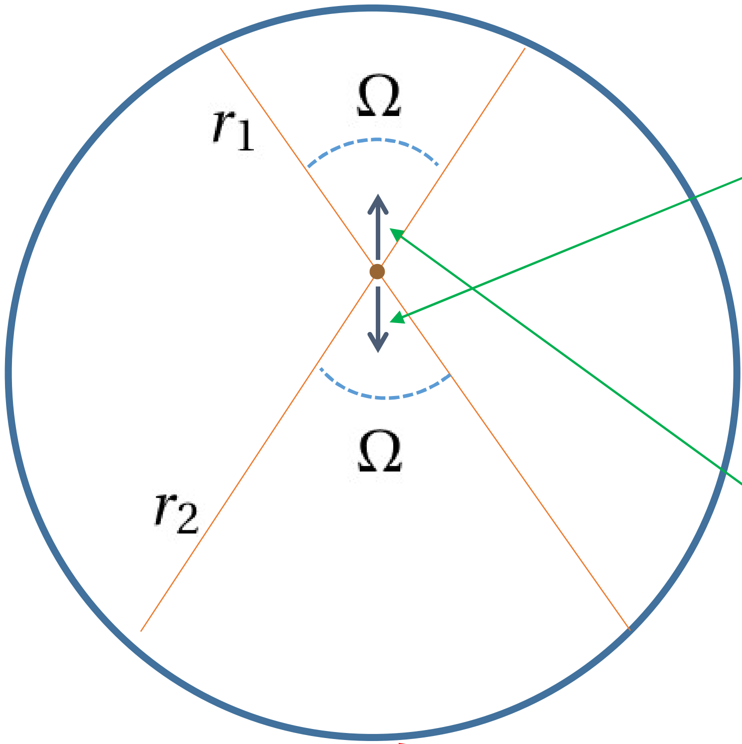
Constant surface charge (3D) (C/m²)



$\varrho_s > 0$



$Q_1 = \varrho_s r_1^2 \Omega$



$$E_1 \sim \frac{Q_1}{r_1^2} = \Omega \varrho_s$$

$$\boxed{E_1 = E_2}$$

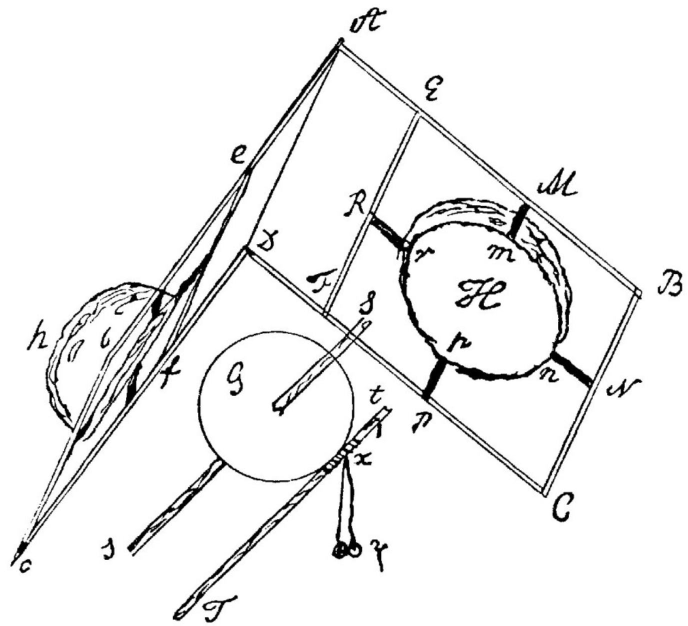
$$E_2 \sim \frac{Q_2}{r_2^2} = \varrho_s \Omega$$

$Q_2 = \varrho_s r_2^2 \Omega$

Internal field zero everywhere!

Henry Cavendish (1731–1810)

$$F \sim \frac{Q_1 Q_2}{r^n}, \quad n = ?$$



$$\boxed{\frac{1}{r^n}} \qquad 2 - \delta < n < 2 + \delta$$

$$\delta < \frac{1}{50}$$

Biot: *Le plus riche de tous les savants, et peut-être le plus savant des riches*

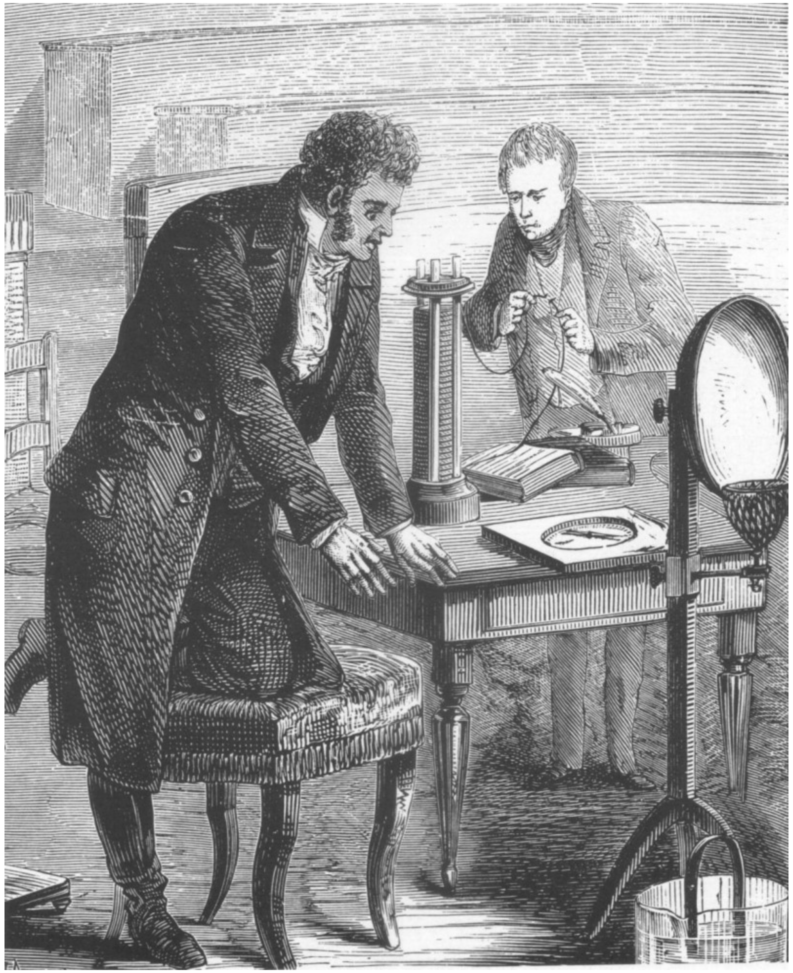
Maxwell

$$\delta < \frac{1}{21600}$$

Plimpton & Lawton (1936)

$$\delta < 2 \cdot 10^{-9}$$

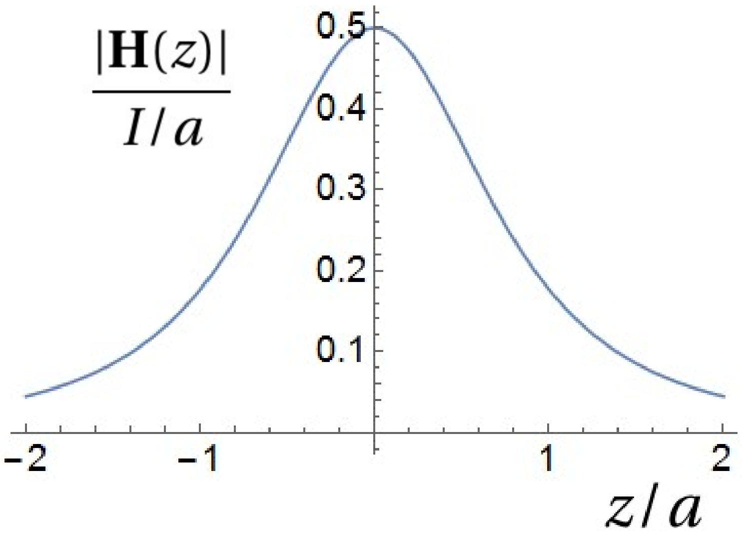
Hans Christian Örsted (1777–1851)

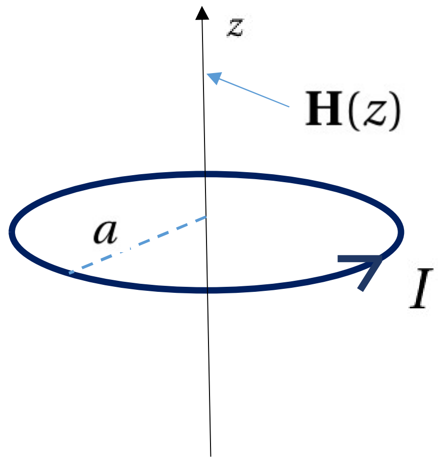



.com


www.norwegian.com
H.C. Ørsted
Danish physicist

Magnetic field of a circular current loop on the symmetry axis





$$\mathbf{H}(z) = \mathbf{a}_z \frac{I a^2}{2(z^2 + a^2)^{3/2}}$$

Näillä tiedoilla voidaan kirjoittaa ympyrämuotoisen virtasilmukan magneettikentän tarkaksi kaavaksi

$$\mathbf{H} = \frac{I}{2\pi\rho\sqrt{(a+\rho)^2+z^2}}\Bigg[-(\mathbf{u}_\varphi \times \mathbf{r})K(k) + \\ + \frac{\mathbf{u}_\rho z(a^2+r^2) + \mathbf{u}_z\rho(a^2-r^2)}{(a-\rho)^2+z^2}E(k)\Bigg]. \qquad (6.186)$$

Tuntuu hiukan epäoikeudenmukaiselta, että kaikkein yksinkertaisimmalle virtalähteelle, ympyränmuotoiselle virralle, saadaan näin monimutkaisen näköinen magneettikentän lauseke!

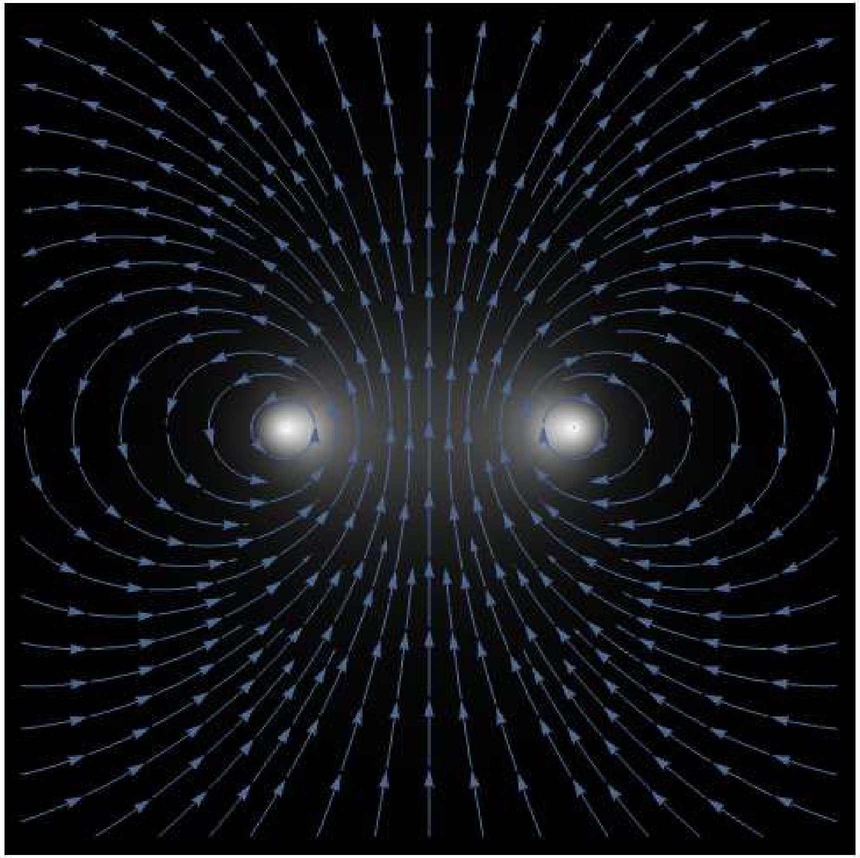
Tulos voidaan kirjoittaa käyttämällä täydellisiä elliptisiä integraaleja, joiden arvot voidaan laskea tai katsoa taulukoista:

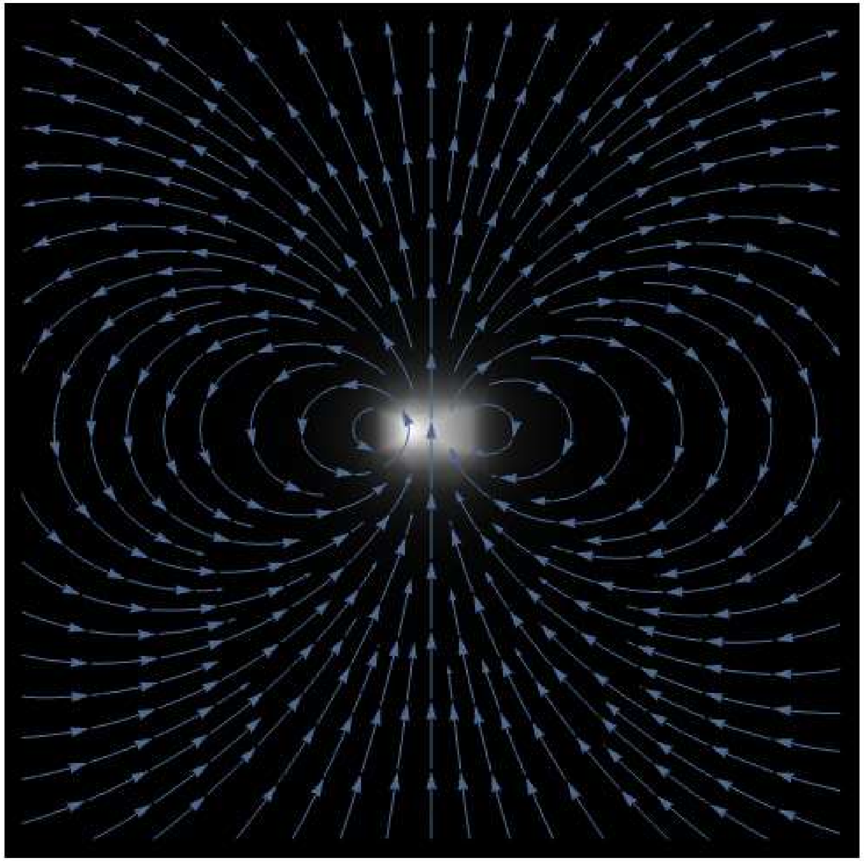
$$K(k) = \int_0^{\pi/2} \frac{d\alpha}{\sqrt{1-k^2\sin^2\alpha}}, \qquad (6.176)$$

$$E(k) = \int_0^{\pi/2} \sqrt{1-k^2\sin^2\alpha}\, d\alpha. \qquad (6.177)$$

Nämä ovat *ensimmäisen ja toisen lajin täydelliset elliptiset integraalit*[3] ja niiden avulla saadaan vektoripotentiaali muotoon

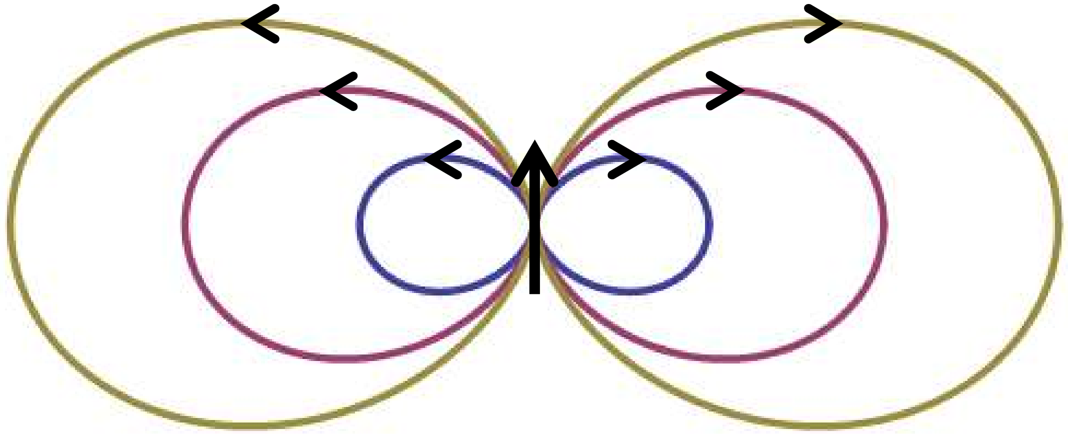
Magnetic field of a current loop





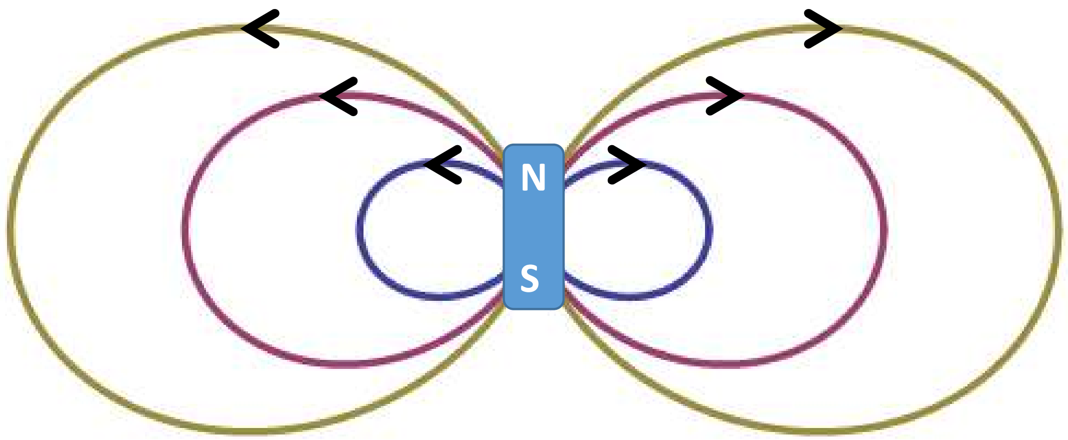
Electric dipole field

$$\mathbf{E}(\mathbf{R}) = \frac{p_e}{4\pi\varepsilon_0 R^3}\left(\mathbf{a}_R\, 2\cos\theta + \mathbf{a}_\theta \sin\theta\right)$$



Magnetic dipole field

$$\mathbf{H}(\mathbf{R}) = \frac{p_m}{4\pi\mu_0 R^3}\left(\mathbf{a}_R\, 2\cos\theta + \mathbf{a}_\theta \sin\theta\right)$$



B-5 RELATIVE PERMEABILITIES†

Material	Relative Permeability, μ_r
Ferromagnetic (nonlinear)	
Nickel	250
Cobalt	600
Iron (pure)	4,000
Mumetal	100,000
Paramagnetic	
Aluminum	1.000021
Magnesium	1.000012
Palladium	1.00082
Titanium	1.00018
Diamagnetic	
Bismuth	0.99983
Gold	0.99996
Silver	0.99998
Copper	0.99999

(from Cheng: Appendix B)

B-3 RELATIVE PERMITTIVITIES (DIELECTRIC CONSTANTS)†

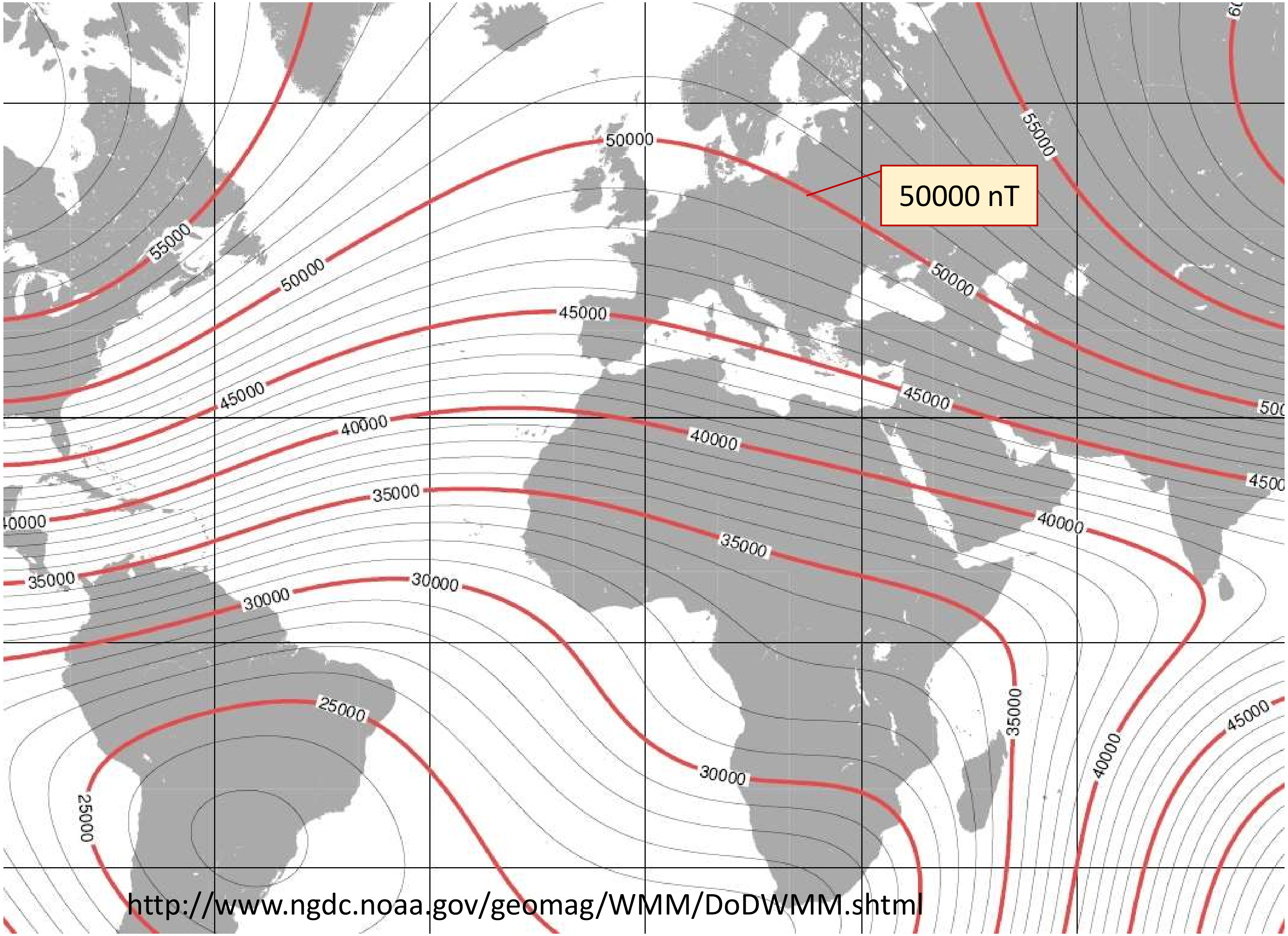
Material	Relative Permittivity, ϵ_r
Air	1.0
Bakelite	5.0
Glass	4–10
Mica	6.0
Oil	2.3
Paper	2–4
Paraffin wax	2.2
Plexiglass	3.4
Polyethylene	2.3
Polystyrene	2.6
Porcelain	5.7
Rubber	2.3–4.0
Soil (dry)	3–4
Teflon	2.1
Water (distilled)	80
Seawater	72

(from Cheng: Appendix B)

B-4 CONDUCTIVITIES†

Material	Conductivity, σ(S/m)	Material	Conductivity, σ(S/m)
Silver	6.17×10^7	Fresh water	10^{-3}
Copper	5.80×10^7	Distilled water	2×10^{-4}
Gold	4.10×10^7	Dry soil	10^{-5}
Aluminum	3.54×10^7	Transformer oil	10^{-11}
Brass	1.57×10^7	Glass	10^{-12}
Bronze	10^7	Porcelain	2×10^{-13}
Iron	10^7	Rubber	10^{-15}
Seawater	4	Fused quartz	10^{-17}

(from Cheng: Appendix B)



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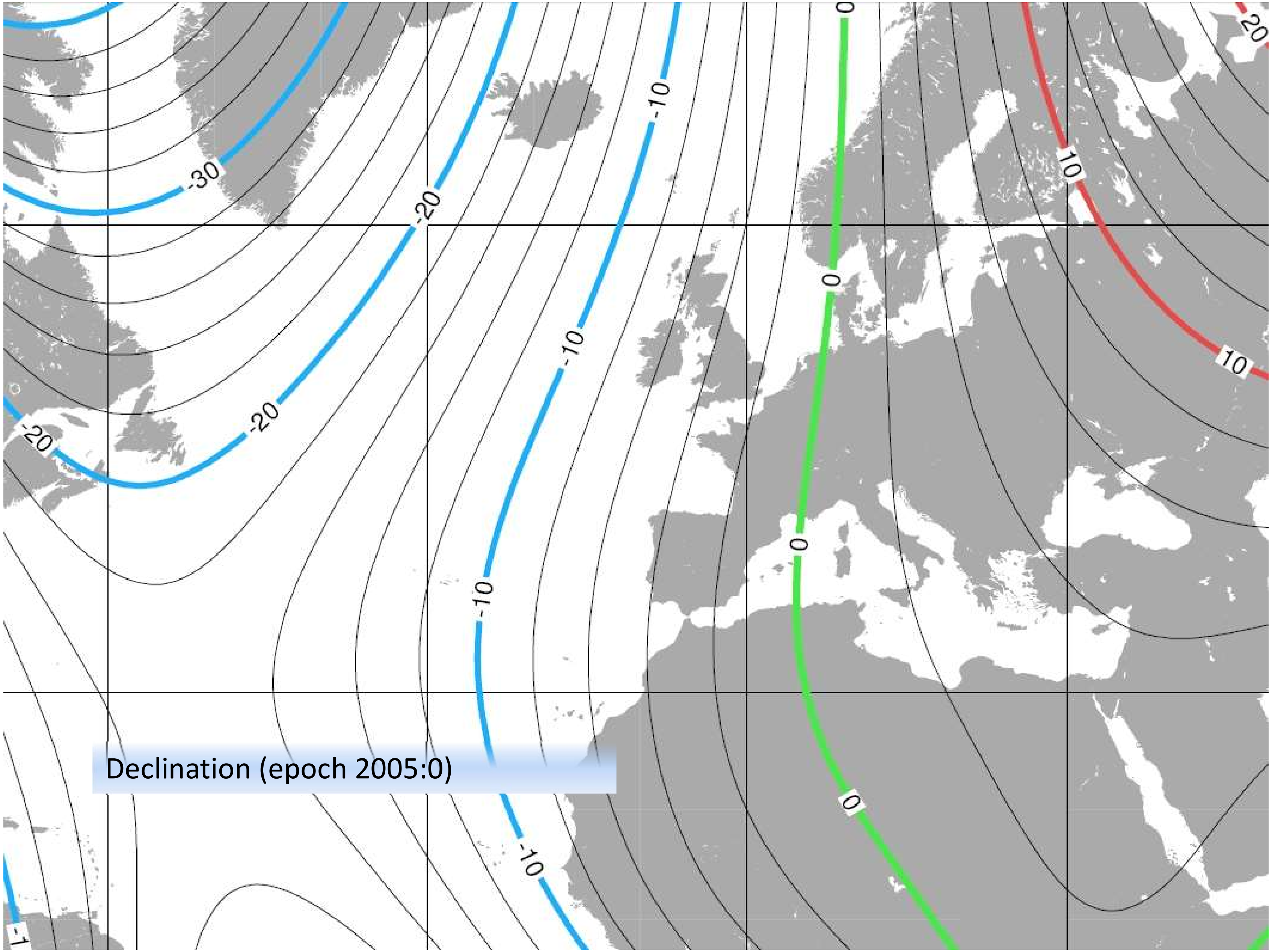
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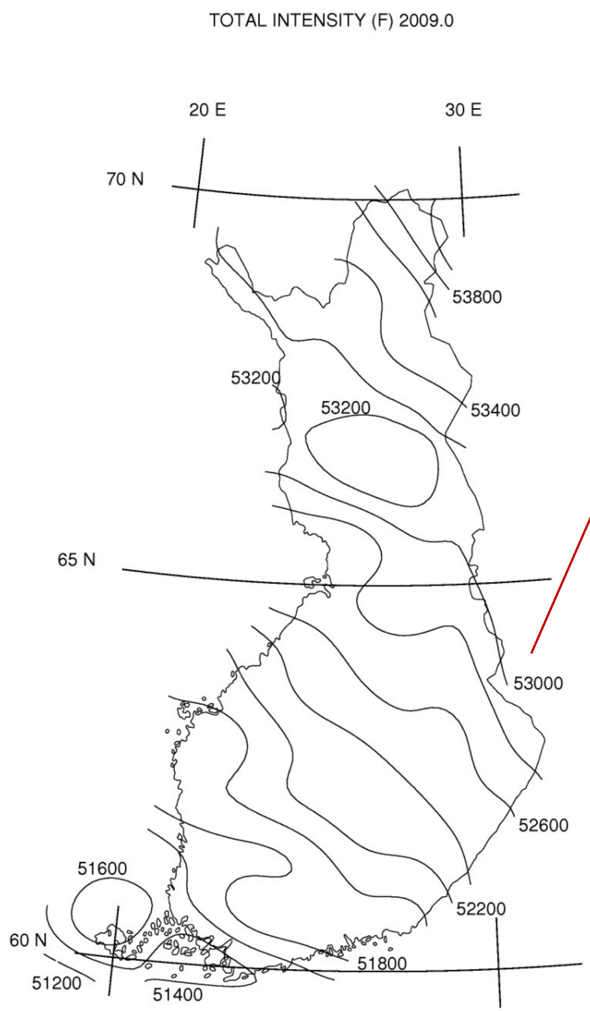
Declination (epoch 2005:0)


TOTAL INTENSITY (F) 2009.0
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60 N
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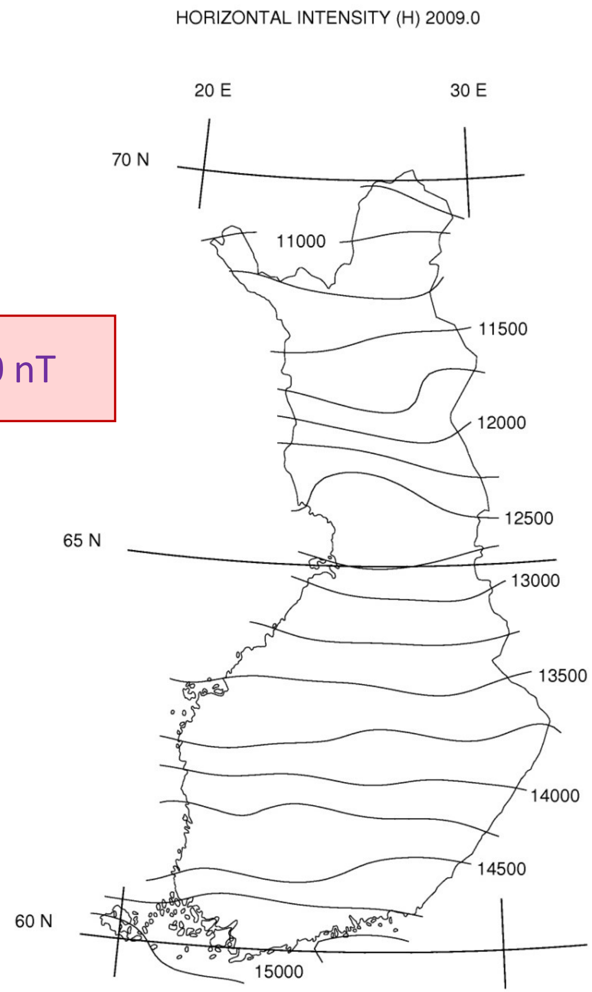
53000 nT


HORIZONTAL INTENSITY (H) 2009.0
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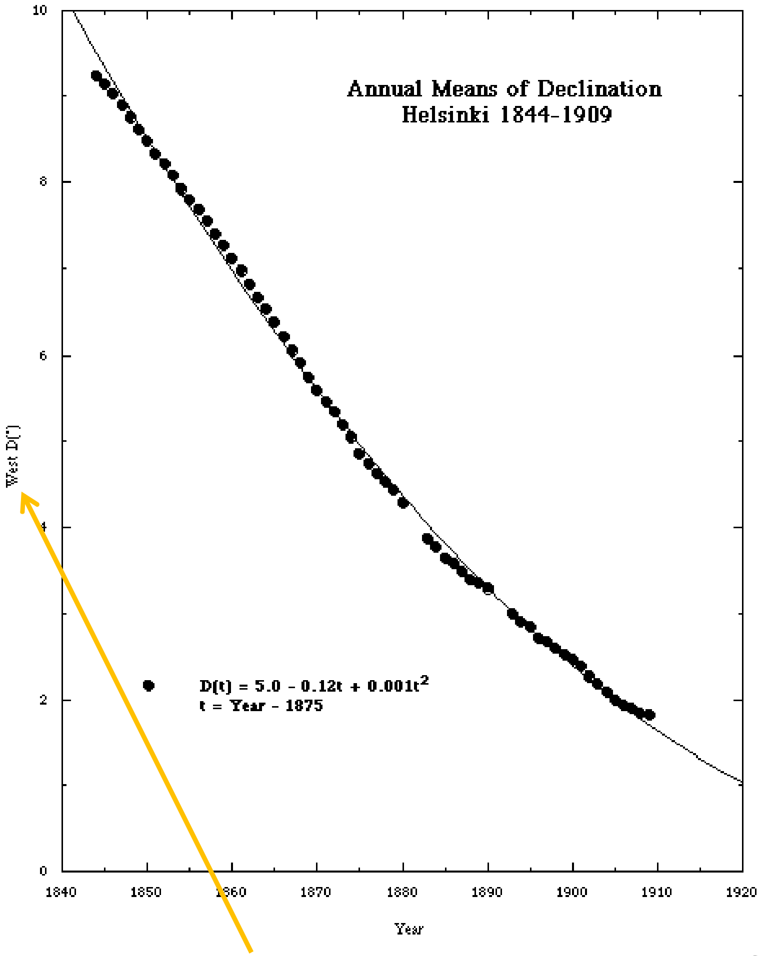
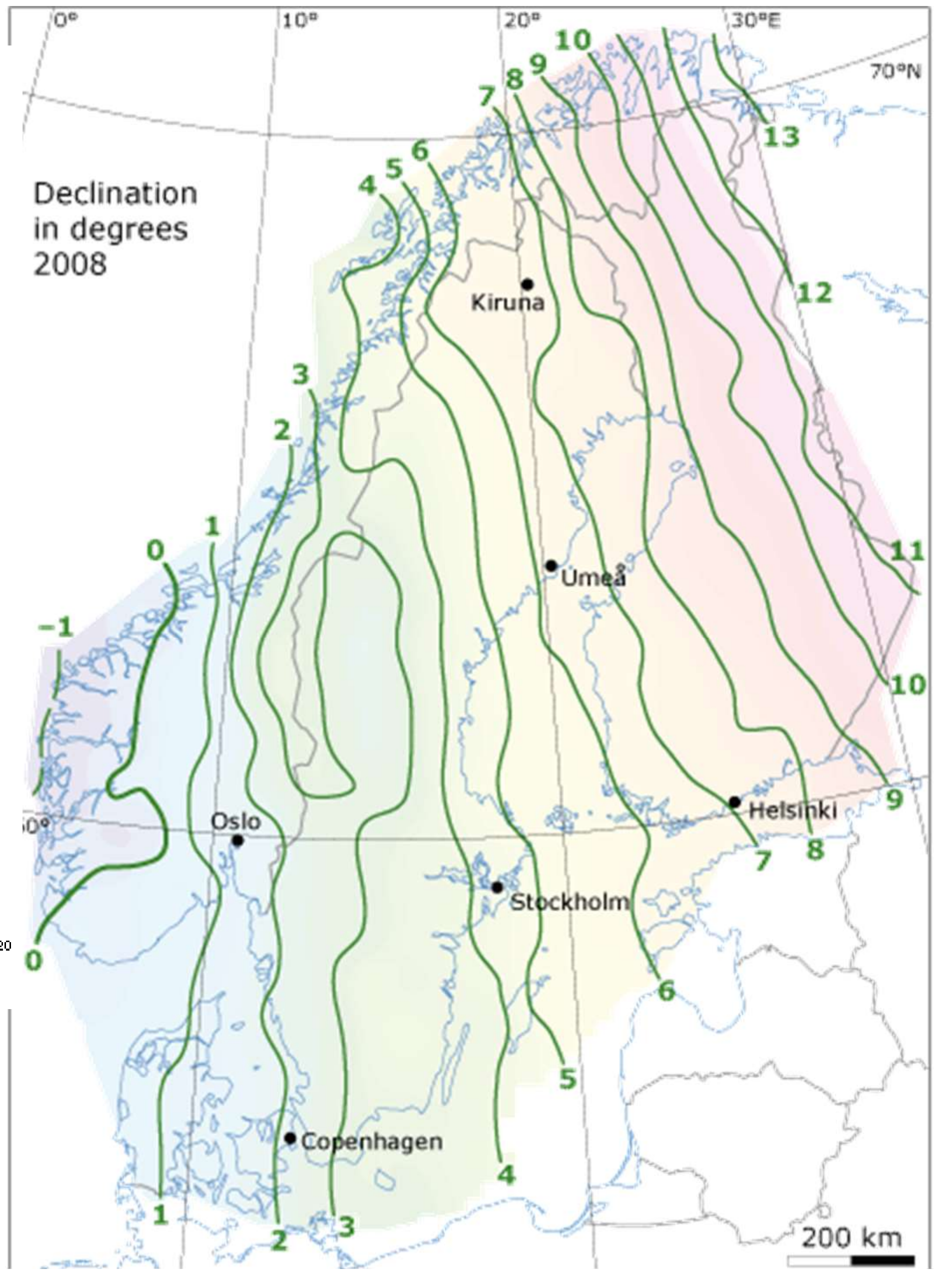
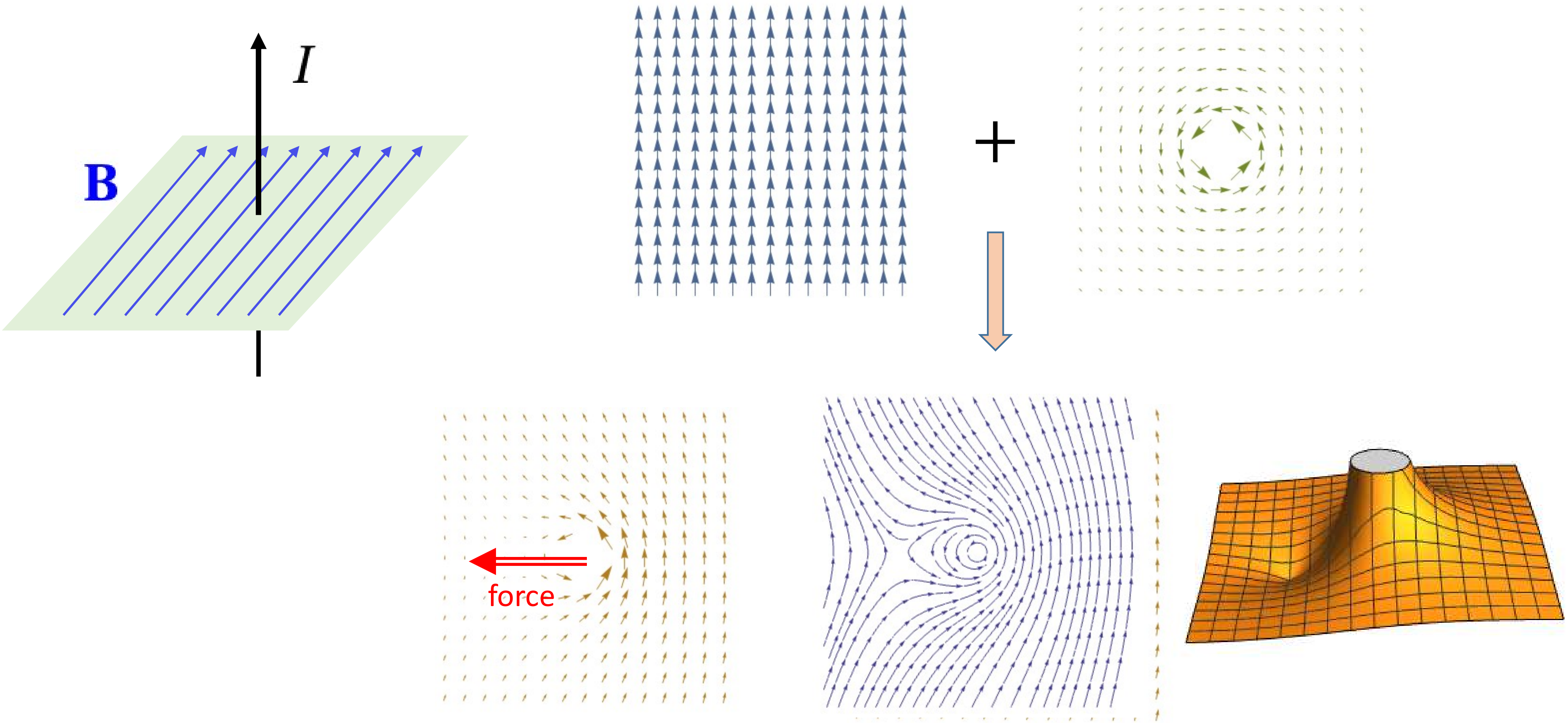


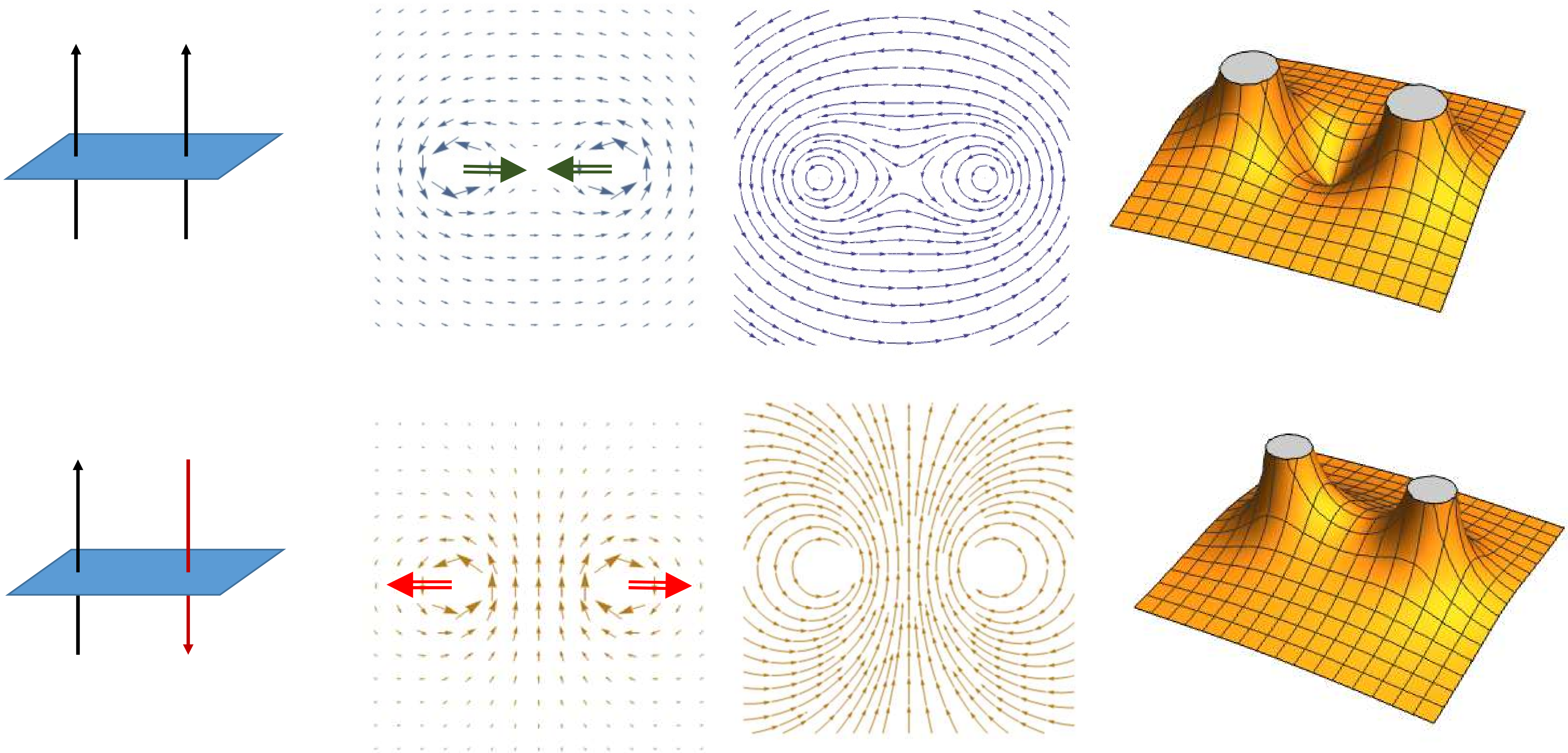
Declination has been toward West.
Today it is to East!



Straight current wire in magnetic field



The force between two straight current wires



André-Marie Ampère (1775–1836)

THÉORIE MATHÉMATIQUE

DES PHÉNOMÈNES

ÉLECTRO-DYNAMIQUES

UNIQUEMENT

DÉDUITE DE L'EXPÉRIENCE

PAR

André-Marie AMPÈRE

NOUVEAU TIRAGE
augmenté d'un Avant-Propos
de M. Edmond BAUER
Professeur à la Sorbonne
et d'un portrait de l'Auteur

PARIS
LIBRAIRIE SCIENTIFIQUE ALBERT BLANCHARD
3, Rue de Médicis

1958

Bureau International
des Poids et Mesures

(old definition of ampere) (until 2019)

8th edition 2006

Organisation Intergouvernementale
de la Convention du Mètre

The International System of Units (SI)

2.1.1.4 Unit of electric current (ampere)

Electric units, called "international units", for current and resistance, were introduced by the International Electrical Congress held in Chicago in 1893, and definitions of the "international ampere" and "international ohm" were confirmed by the International Conference in London in 1908.

Although it was already obvious on the occasion of the 8th CGPM (1933) that there was a unanimous desire to replace those "international units" by so-called "absolute units", the official decision to abolish them was only taken by the 9th CGPM (1948), which adopted the ampere for the unit of electric current, following a definition proposed by the CIPM (1946, Resolution 2; PV, **20**, 129-137):

> **The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.**

It follows that the magnetic constant, μ_0, also known as the permeability of free space, is exactly $4\pi \times 10^{-7}$ henries per metre, $\mu_0 = 4\pi \times 10^{-7}$ H/m.

The expression "MKS unit of force" which occurs in the original text of 1946 has been replaced here by "newton", a name adopted for this unit by the 9th CGPM (1948, Resolution 7; CR, 70).

starting from May 20, 2019:

The ampere is defined by taking the fixed numerical value of the elementary charge e to be $1.602176634 \times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{Cs}$.

starting from May 20, 2019:

The ampere is defined by taking the fixed numerical value of the elementary charge e to be $1.602176634 \times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{Cs}$.

The second is defined by taking the fixed numerical value of the cesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the cesium-133 atom, to be 9,192,631,770 when expressed in the unit Hz, which is equal to s^{-1}.

The meter is defined by taking the fixed numerical value of the speed of light in vacuum c to be 299,792,458 when expressed in the unit m s^{-1}, where the second is defined in terms of $\Delta\nu_{Cs}$.