Weber’s Planetary Model of the Atom

A. K. T. Assis

University of Campinas – Brazil

www.ifi.unicamp.br/~assis

Wilhelm Weber (1804 – 1891)

J. C. Maxwell (1831 – 1879)

Professor of physics at Göttingen University working in collaboration with Gauss

Coulomb (1785): $$\vec{F} = \frac{q_1 q_2}{4\pi\varepsilon_0} \frac{\hat{r}}{r^2}$$

Ampère (1822): $$\vec{F} = -\frac{\mu_0}{4\pi} I_1 I_2 \frac{\hat{r}}{r^2} f(\alpha, \beta, \gamma)$$

Faraday (1831): $$emf = -M \frac{dI}{dt}$$

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Weber's hypothesis: $$Id\vec{\ell} \Leftrightarrow q\vec{v}$$

Weber's force: $$\vec{F} = \frac{q_1 q_2}{4\pi\varepsilon_0}\frac{\hat{r}}{r^2}\left[1 + K_1 v_1 v_2 + K_2 (a_1 - a_2)\right]$$

Weber's force (1846):

$$\vec{F} = \frac{q_1 q_2}{4\pi\varepsilon_0} \frac{\hat{r}}{r^2} \left(1 - \frac{\dot{r}^2}{2c^2} + \frac{r\,\ddot{r}}{c^2} \right)$$

$$\dot{r} = \frac{dr}{dt}, \qquad \ddot{r} = \frac{d^2 r}{dt^2}, \qquad c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

Weber measured $\boldsymbol{c}$ in 1856: $\boldsymbol{c} = 3 \times 10^8$ m/s.

Therefore, connection between electromagnetism and optics <u>before</u> Maxwell!

Properties of Weber's force

- In the static case ($dr/dt = 0$ and $d^2r/dt^2 = 0$) we return to the laws of Coulomb and Gauss.
- Action and reaction: Conservation of linear momentum.
- Force along the straight line connecting the particles: Conservation of angular momentum.
- It can be deduced from a velocity dependent potential energy:

$$U = \frac{q_1 q_2}{4\pi\varepsilon_0}\frac{1}{r}\left(1 - \frac{\dot{r}^2}{2c^2}\right)$$

- Conservation of energy:

$$\frac{d(K+U)}{dt} = 0$$

- Faraday’s law of induction can be deduced from Weber’s force (see Maxwell, *Treatise*, Vol. 2, Chap. 23).
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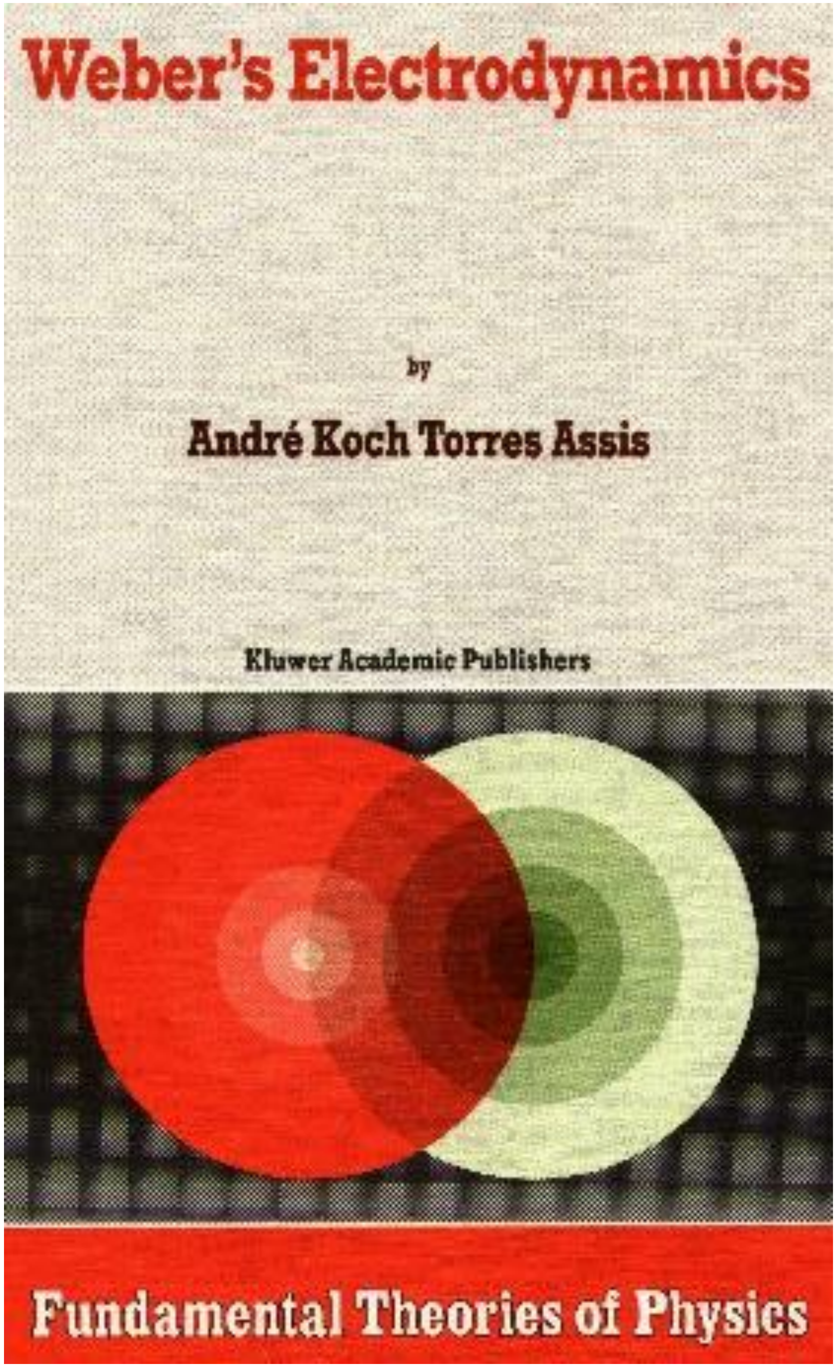
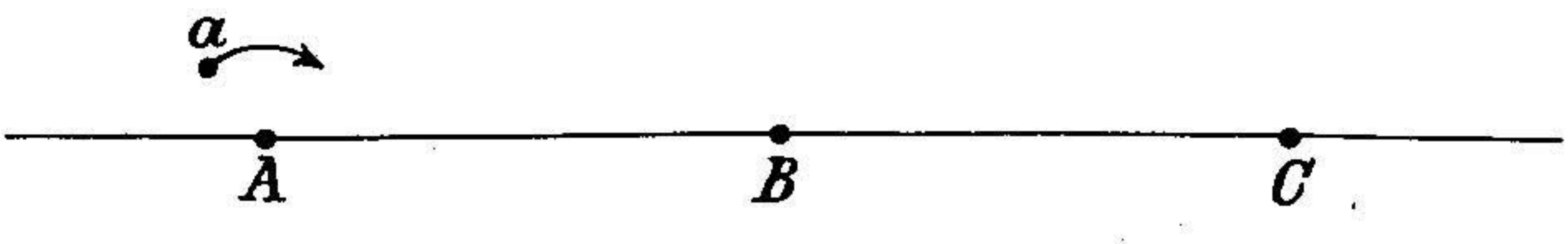
- Weber’s force is completely **relational**. It depends only on r, dr/dt and d^2r/dt^2. It has the same value for all observers and in all systems of reference. It depends only on magnitudes intrinsic to the system of interacting charges. It depends only on the relation between the bodies.



1994
Kluwer
(Springer)

Weber's drawing and words in 1852 considering a negative charged particle ***a*** following an elliptical orbit around a positive ponderable electrical mass ***A*** fixed in the metal lattice:

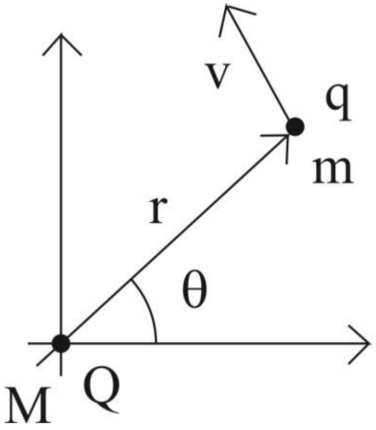


"As a result, the mass at ***a*** will describe, for instance, an elliptical orbit around ***A***, according to Kepler's laws."

<u>This supposition is at the origin of Weber's planetary model of the atom.</u>

In 1871 Weber solved approximately the two-body problem with his force law:

a) Particles with charges of opposite sign: $qQ < 0$.



Central force: conservation of angular momentum

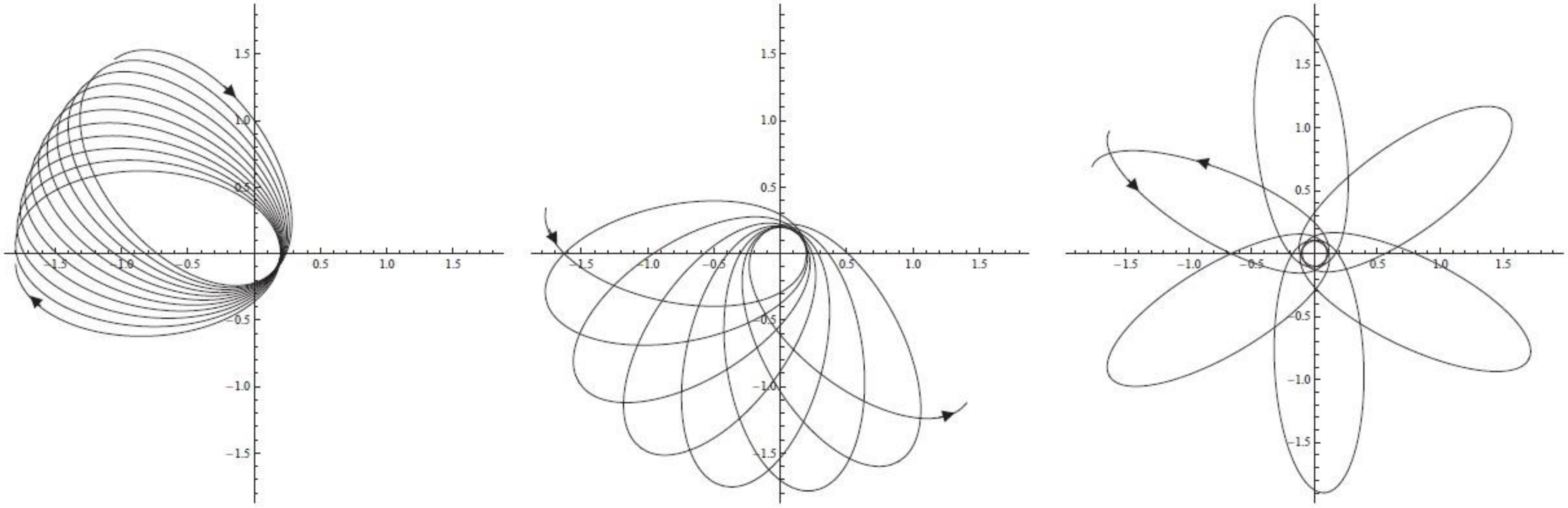
$$L = mr^2 \frac{d\theta}{dt} = \text{constant}$$

Weber's law also complies with conservation of energy:
The sum of the kinetic and potential energies is constant in time.

$$E = K + U = \frac{m}{2}\left(\dot{r}^2 + r^2\dot{\theta}^2\right) + \frac{qQ}{4\pi\,\varepsilon_o}\frac{1}{r}\left(1 - \frac{\dot{r}^2}{2c^2}\right) = \text{constant}$$

There is a general solution of this equation in terms of the incomplete elliptic integral of the second kind.

This solution yields an elliptical orbit with a precession of the perihelion:



(a) (b) (c)

b) We now consider the two-body problem for Weber's force law when the particles have charges of the same sign, $q_1 q_2 > 0$.

This case presents the main difference not only with classical electrodynamics (Coulomb's force) but also with modern physics (quantum mechanics and nuclear physics).

Weber's planetary model of the atom (1870-1880):

$$\frac{q_1 q_2}{4\pi\varepsilon_0}\frac{1}{r^2}\left(1-\frac{\dot{r}^2}{2c^2}+\frac{r\,\ddot{r}}{c^2}\right)\approx\frac{q_1 q_2}{4\pi\varepsilon_0}\frac{1}{r^2}+\frac{q_1 q_2}{4\pi\varepsilon_0 r c^2}a=ma$$

$$\frac{q_1 q_2}{4\pi\varepsilon_0}\frac{1}{r^2}=\left(m-\frac{q_1 q_2}{4\pi\varepsilon_0 r c^2}\right)a$$

$$m=\frac{q_1 q_2}{4\pi\varepsilon_0 r c^2}$$ when $$r=\frac{q_1 q_2}{4\pi\varepsilon_0 m c^2}=r_C$$

Therefore, if $r < r_C$

Then $m-\frac{q_1 q_2}{4\pi\varepsilon_0 r c^2} < 0$

The particles will behave as if they had a **<u>negative</u>** inertial mass. Therefore, two particles with charges of the same sign will attract one another, instead of repelling each other!!!

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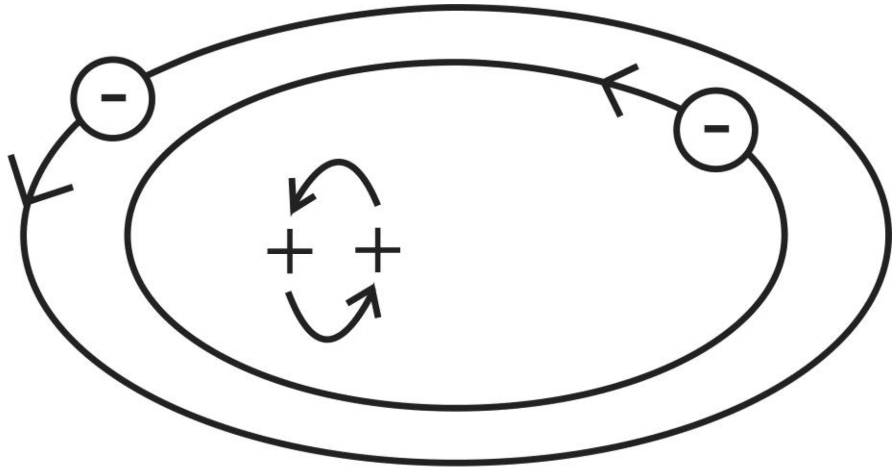
$$\frac{q_1 q_2}{4\pi\varepsilon_0}\frac{1}{r^2}=\left(m-\frac{q_1 q_2}{4\pi\varepsilon_0 r c^2}\right)a$$

$m=\dfrac{q_1 q_2}{4\pi\varepsilon_0 r c^2}$ when $r=\dfrac{q_1 q_2}{4\pi\varepsilon_0 m c^2}=r_C$

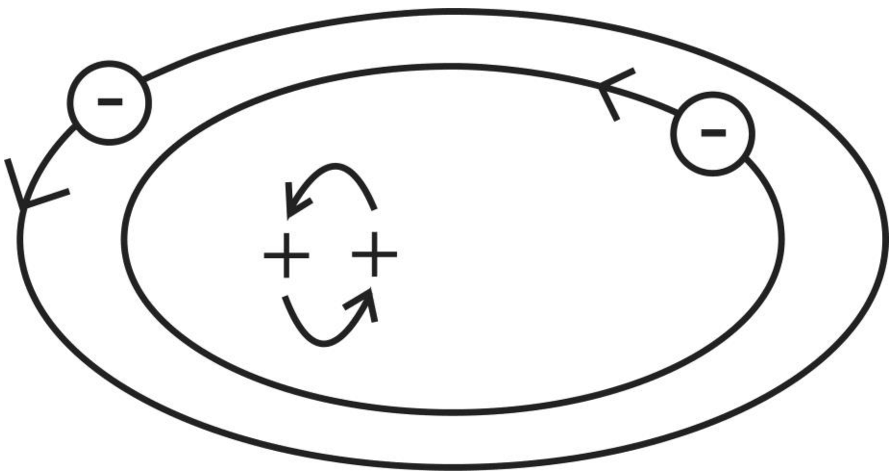
This property gave rise to Weber's remarkable planetary model of the atom:



If we insert the known values of the masses and charges of two positrons, we obtain that the critical distance is given by

$$r_C = 10^{-15} m$$

Therefore, according to Weber's electrodynamics, two positrons attract one another for distances *r* smaller than 10^{-15} m.



Weber wrote in the beginning of the 1880's his eighth and last major memoir on Electrodynamic Measurements. It was published posthumously in 1894. It contains his mature planetary model of the atom.

Particles with charges of the same sign would attract one another when they were separated by distances smaller than his "critical distance" r_C. They would be in "molecular motions". These particles would form "indivisible molecules" or the nuclei of his planetary atoms. He characterized them in a beautiful way by saying that this group formed an enclosed world for itself, due to the fact that the internal force connecting the group would be so great that it would be extremely difficult to break it apart due to external influences. His words:

"Additionally, not only two or three, but a far larger number of *similar electric particles* could be together in such a small space, without the distance of any particle from another being greater than or equal to r_C, so that all of these particles together, also form an *indivisible molecule which remains together for ever*."

"Each such composite molecule forms an enclosed world for itself."

In the 1880's Weber tried to explain qualitatively the properties of the elements of the periodic table utilizing his planetary model of the atom. He also tried to explain the chemical bondings between atoms. At the right we have some of his models of the atom:

$$\begin{bmatrix} +1 \\ -1 \end{bmatrix}$$

$$\begin{bmatrix} -2 \\ +1 \\ +1 \end{bmatrix} \quad \begin{bmatrix} +2 \\ -2 \end{bmatrix} \quad \begin{bmatrix} +2 \\ -1 \\ -1 \end{bmatrix} \quad \begin{bmatrix} +1 \\ +1 \\ -1 \\ -1 \end{bmatrix}$$

The modern atom with a nucleous composed of n protons surrounded by n electrons describing elliptical orbits around the nucleous corresponds approximately to the following Weberian "ponderable molecule":

$$\begin{bmatrix} +n \\ -1 \\ \dots \\ -1 \end{bmatrix}$$

This Weberian atom has n particles of charge $+q$ and mass M attracting each other and moving relative to one another inside a volume of diameter r_C. This stable positive nucleous is surrounded by n particles of charge $-q$ and mass m describing elliptical orbits around the nucleous.

Remarkable properties of Weber's planetary model of the atom:

- Weber's **prediction** (1870-1880) was made before the discovery of the electron (1897), of Balmer's spectral series (1897) and of Rutherford's scattering experiments (1911)! Bohr's model (1913), on the other hand, was **created (invented)** in order to be compatible with these experimental findings.

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• Weber presented a formula for his critical distance r_c below which two charges of the same sign would attract one another. But he could not calculate its value as the electrons and positrons (1932) were unknown. When we utilize the modern values of the mass and charge of two positrons, we obtain that they will attract each other when **r < r_C = 10^{-15} m**. Therefore, Weber's model gives a **justification** for the known size of the atomic nuclei!

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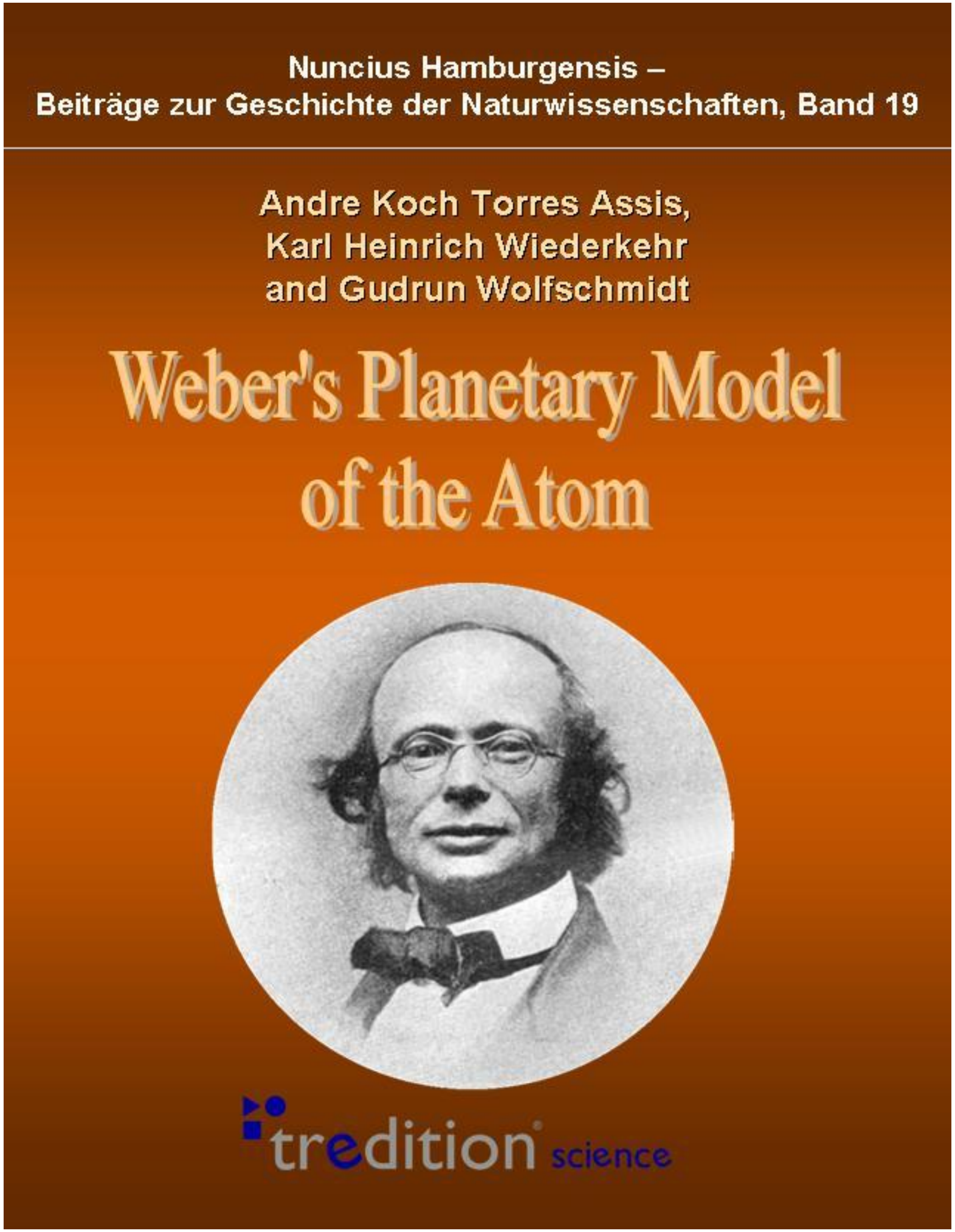
• In modern physics it is necessary to **postulate** the existence of nuclear forces in order to stabilize the positively charged nucleous against Coulomb's repulsive forces. Weber's model, on the other hand, offers an **unification** of electromagnetism with nuclear physics, as the nucleus is held together by purely electrodynamic forces!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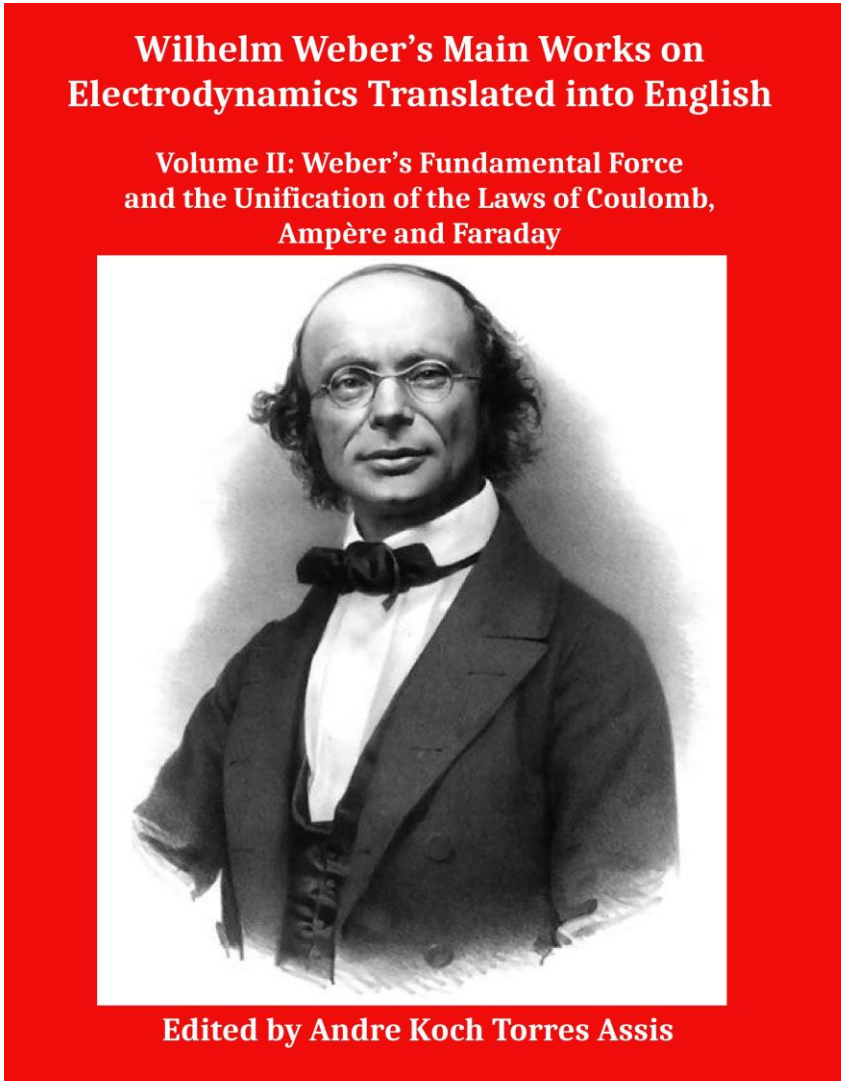

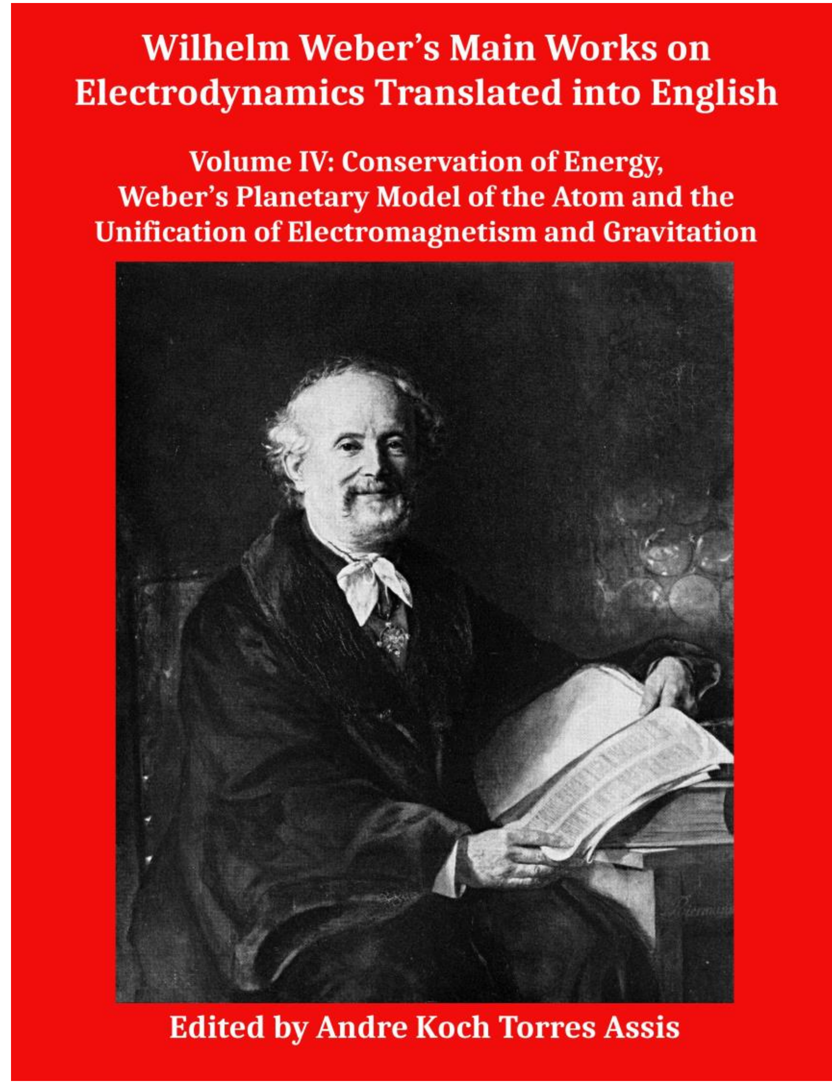

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Conclusion

Weber's electrodynamics is extremely powerful.

Weber's planetary model of the atom presents a justification for the known size of the nuclei. It represents the essence of the correct explanation of the constitution of real atoms. It explains the stability of the nuclei with purely electrodynamic forces. This is the unification of nuclear physics with electromagnetism.

In the last few years there has been a renewed interest in Weber's electrodynamics due to novel experiments and new theoretical developments.

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