

# Photoelectric Effect as Resonance Phenomena

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## Abstract

It is explicitly stated in the literature that classical electrodynamics can not explain the photoelectric effect. In my view, there is at least one possibility. The system of metal ion and quasi-free electron can be considered as a resonator. A simple estimation has revealed that its resonance frequency is close to the threshold frequency of the photoeffect.

How do quasi-free electrons move in the metals? I imagine a following model (figure 1). The conducting electrons will not fly through the atoms, otherwise it would then come to the generation of X-rays. The positively charged metal ion generally attracts the outer electron, but the other electrons form the barriers on the way to the nucleus. Therefore they will rather move at the edges of atoms, but at the points of contact between the atoms they pass from one atom to another without or with relatively little resistance.

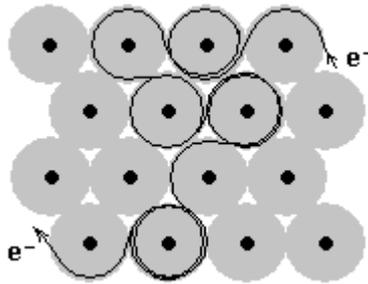


Figure 1

Statistically nothing changes in principle if we disregard the short-term movement of the electrons between the atoms. In this way, we get a simplified model of the metal, which consists of hydrogen-like atoms. For the alkali metals, ie the metals belonging to the same group as hydrogen, this may even be quite true.

The system of metal ion and quasi-free electron can be considered as a resonator. This raises the question of whether there is a relationship between the natural frequencies of such resonators and the corresponding cutoff frequencies of the photo effect? We want to make an estimate.

The quasi-free electron we imagine as an electron cloud and this electron cloud as a homogeneously charged ball. An external electric field causes the shift of the charge: the electron ball shifts relative to the metal ion. Between them arises an electric field, which is equal to the outer field but opposite, so that the outer field is completely

compensated.

The formula for the electric field strength in this case is

$$E = \frac{e}{4\pi\epsilon_0 R_0^3} \delta$$

Here are  $R_0$  – the radius of the charged ball, which represents the electron, and at the same time its radius corresponds to the total atomic radius.  $\delta$  – the shift of the electron-ball relative to the metal ion.

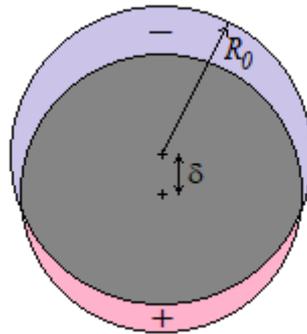


Figure 2

This field strength acts on the charge of the electron, resulting in the force that tries to bring the electron back to its rest position:

$$F = \frac{e^2}{4\pi\epsilon_0 R_0^3} \delta$$

As we can see, retroactive force is directly proportional to the shift. So we're getting to Hooke's Law. That's no wonder, because the metals are inherently elastic. This is as well an indirect confirmation of our simplified model. Thus we get the formula for both harmonic potential

$$U = \frac{1}{2} \frac{e^2}{4\pi\epsilon_0 R_0^3} \delta^2$$

and spring constant

$$k = \frac{e^2}{4\pi\epsilon_0 R_0^3}$$

Of course, the harmonic potential is an approximation, but very often used. In addition, we are primarily concerned with whether it is possible in principle to

explain the photoelectric effect by means of the resonance process. Logically, when the frequency of the external electric field coincides with the natural frequency of the conducting electrons, the resonant phenomenon occurs and the conducting electron is thrown out of the atom and finally out of the Metall.

The resonance frequency is given by the formula

$$f^r = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

and applied to our model

$$f^r = \frac{e}{4\pi\sqrt{\pi\epsilon_0 R_0^3 m_e}}$$

In [1] we find the radii of the alkali atoms in metallic bonding

$$R_{Li} = 1.52 \cdot 10^{-10} m, R_{Na} = 1.86 \cdot 10^{-10} m, R_K = 2.27 \cdot 10^{-10} m, R_{Rb} = 2.48 \cdot 10^{-10} m, R_{Cs} = 2.65 \cdot 10^{-10} m$$

and calculate the natural frequencies

$$f_{Li}^r = 1.35 \cdot 10^{15} Hz, f_{Na}^r = 9.99 \cdot 10^{14} Hz, f_K^r = 7.41 \cdot 10^{14} Hz, f_{Rb}^r = 6.49 \cdot 10^{14} Hz, f_{Cs}^r = 5.87 \cdot 10^{14} Hz$$

Now we have to compare these frequencies with the threshold frequencies of the photo effect for the same elements. However, I could not find an extensive table. On the other hand, in [2, 3] is presented the following table for the work function (the energy in  $eV$  ).

**Tab. 4.2** Austrittsarbeiten der Elemente in eV (polykristalline Proben, nach Michaelsen [Michaelson, 1977, Nr. 355])

|      |      |     |      |      |      |      |      |      |      |      |      |      |      |      |      |
|------|------|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Li   | Be   |     |      |      |      |      |      |      |      |      |      | B    | C    |      |      |
| 2.9  | 4.98 |     |      |      |      |      |      |      |      |      |      | 4.45 | 5.0  |      |      |
| Na   | Mg   |     |      |      |      |      |      |      |      |      |      | Al   | Si   | P    | S    |
| 2.75 | 3.66 |     |      |      |      |      |      |      |      |      |      | 4.28 | 4.85 | -    | -    |
| K    | Ca   | Sc  | Ti   | V    | Cr   | Mn   | Fe   | Co   | Ni   | Cu   | Zn   | Ga   | Ge   | As   | Se   |
| 2.30 | 2.87 | 3.5 | 4.33 | 4.3  | 4.5  | 4.1  | 4.5  | 5.0  | 5.15 | 4.65 | 4.33 | 4.2  | 5.0  | 3.75 | 5.9  |
| Rb   | Sr   | Y   | Zr   | Nb   | Mo   | Tc   | Ru   | Rh   | Pd   | Ag   | Cd   | In   | Sn   | Sb   | Te   |
| 2.16 | 2.59 | 3.1 | 4.05 | 4.3  | 4.6  | -    | 4.71 | 4.98 | 5.12 | 4.26 | 4.22 | 4.12 | 4.42 | 4.42 | 4.95 |
| Cs   | Ba   | La  | Hf   | Ta   | W    | Re   | Os   | Ir   | Pt   | Au   | Hg   | Tl   | Pb   | Bi   | Po   |
| 2.14 | 2.7  | 3.5 | 3.9  | 4.25 | 4.55 | 4.96 | 4.83 | 5.27 | 5.65 | 5.1  | 4.49 | 3.84 | 4.25 | 4.22 | -    |

Figure 3

The threshold frequency can then be easily calculated by dividing the work function

by the Planck constant. So we get the threshold frequencies for the same elements

$$f_{Li}^t = 7.01 \cdot 10^{14} \text{ Hz}, f_{Na}^t = 6.65 \cdot 10^{14} \text{ Hz}, f_K^t = 5.56 \cdot 10^{14} \text{ Hz}, f_{Rb}^t = 5.22 \cdot 10^{14} \text{ Hz}, f_{Cs}^t = 5.17 \cdot 10^{14} \text{ Hz}$$

We have calculated the resonance frequencies due to the very simplified model, yet they differ little from real measured frequencies. This is especially evident in the diagram (figure 4).

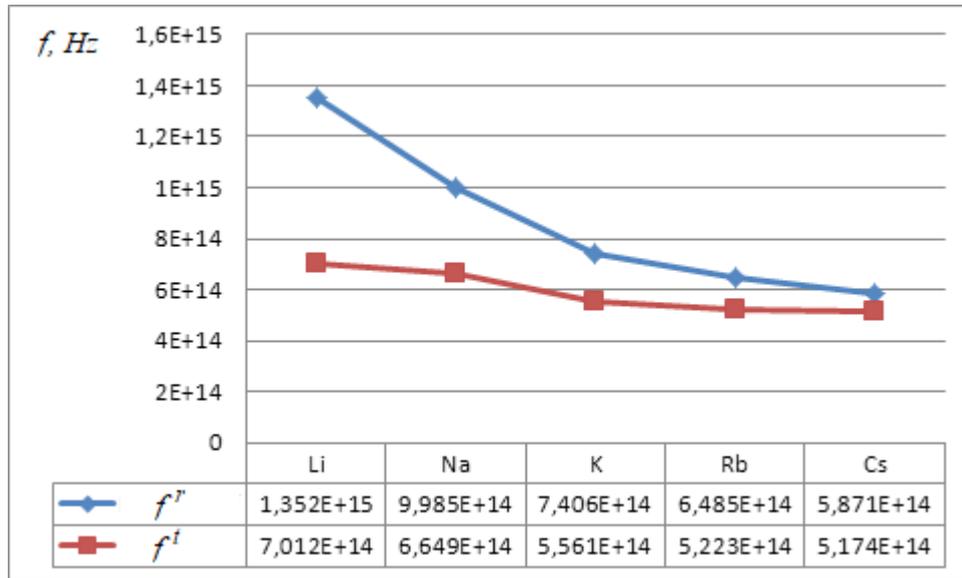


Figure 4

We also have similar results for two neighboring groups (figure 5 and 6).

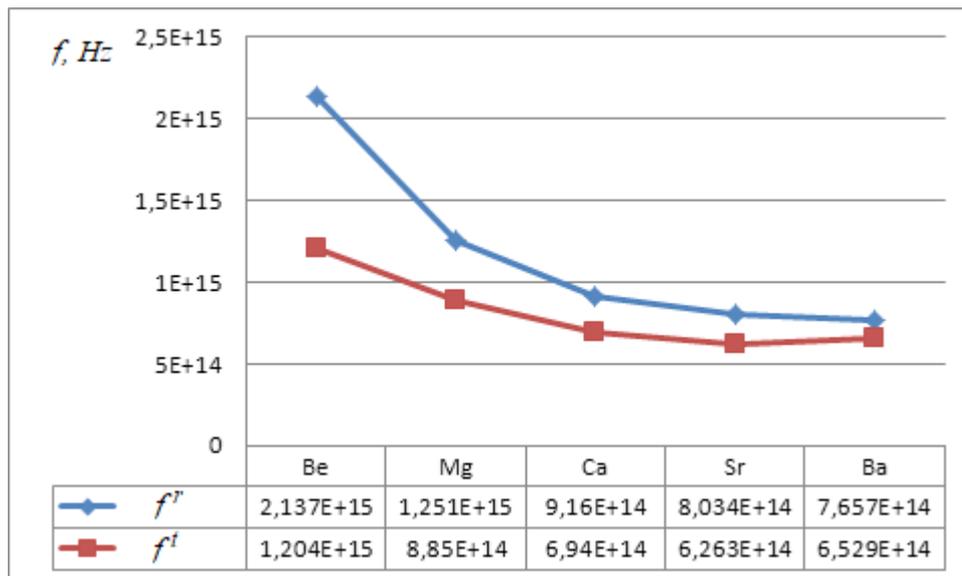


Figure 5

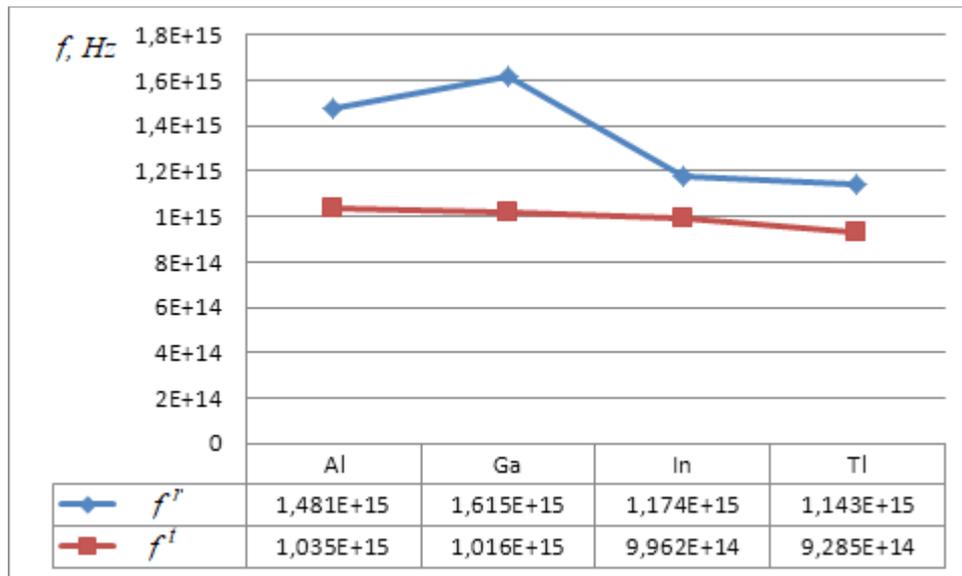


Figure 6

Of course it can not be a coincidence. Further confirmation comes in the examination of the periods (figure 7, 8, 9 and 10).

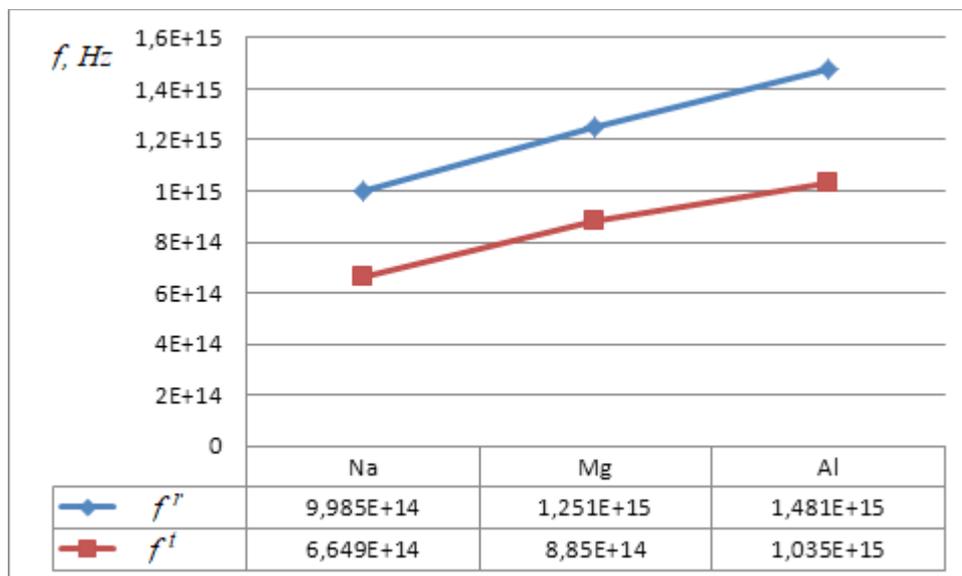


Figure 7

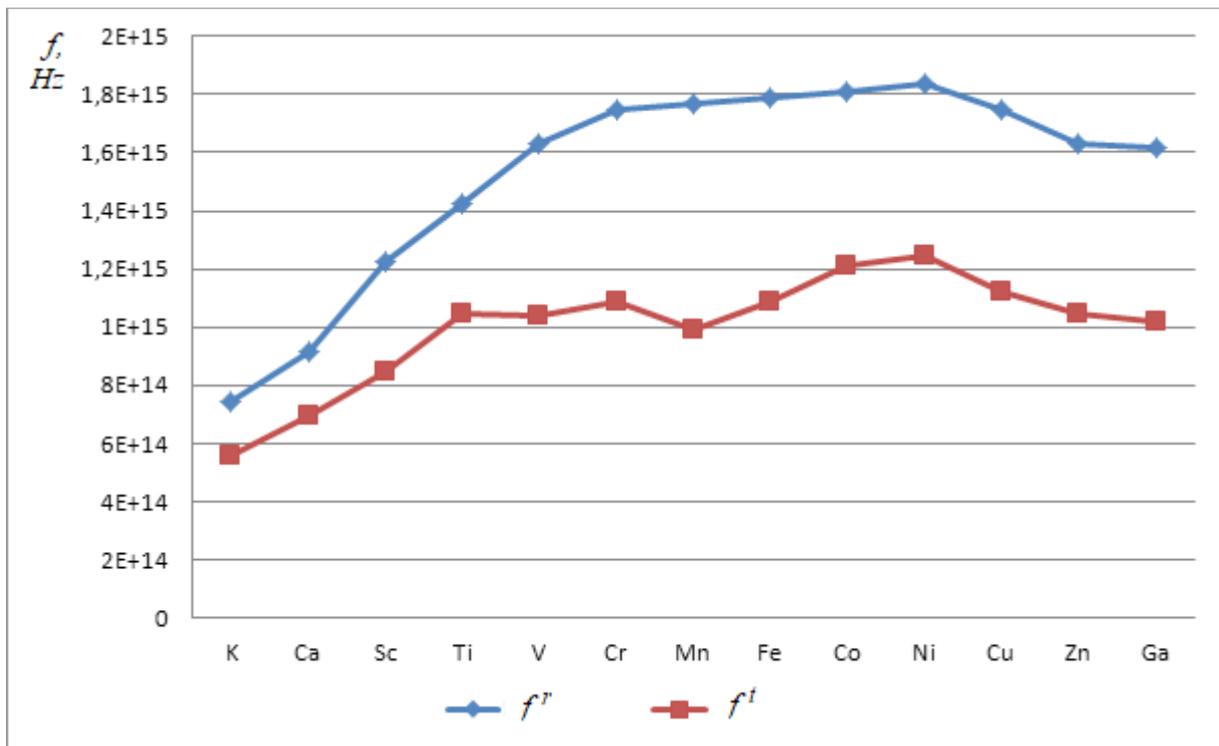


Figure 8

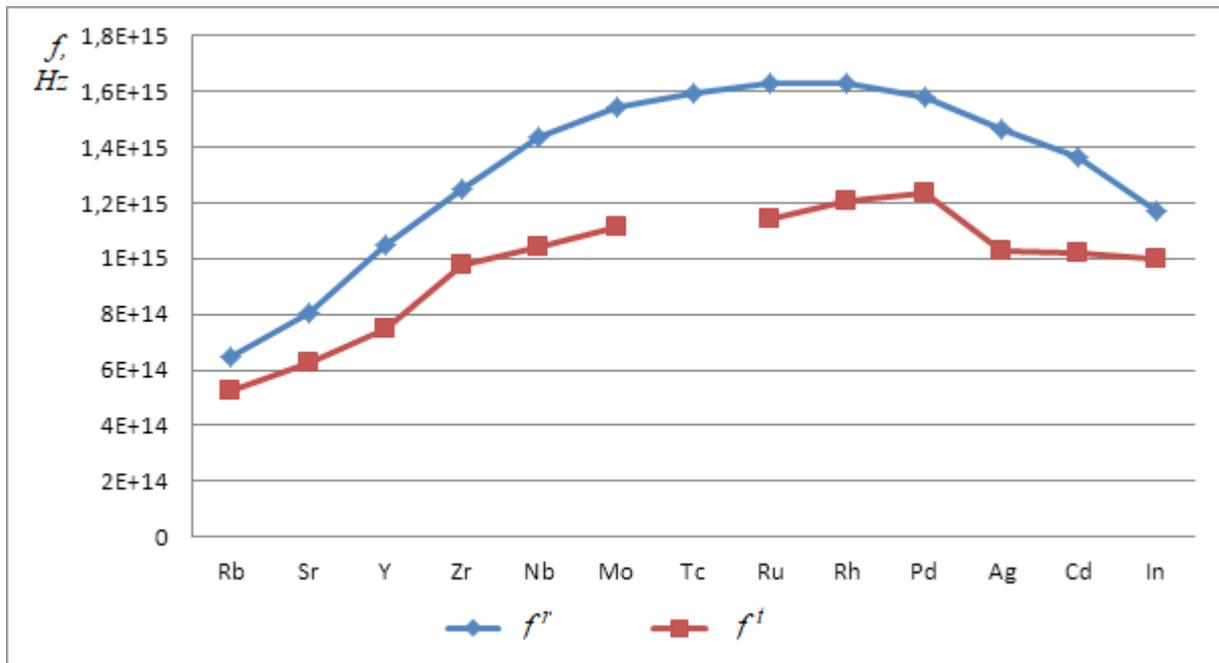


Figure 9

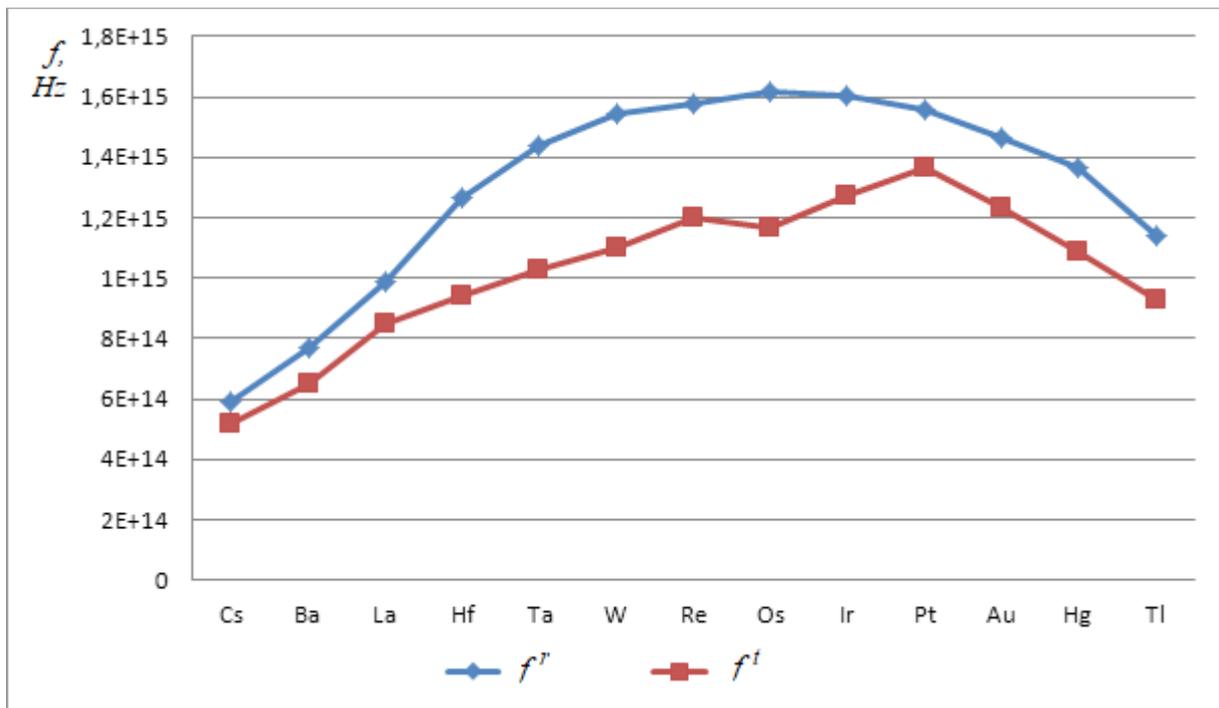


Figure 10

The correlation between resonance and threshold frequencies can not be overlooked. More accurate calculations and better models can even bring more consistency.

**Conclusion:** The resonance can actually be behind the photoelectric effect. This would allow to explain the photoelectric effect also in the context of classical electrodynamics.

[1] Wikipedia. Atomic radii of the elements (data page).  
[http://en.wikipedia.org/wiki/Atomic\\_radii\\_of\\_the\\_elements\\_\(data\\_page\)](http://en.wikipedia.org/wiki/Atomic_radii_of_the_elements_(data_page))

[2] Michaelson, Herbert B. The work function of the elements and its periodicity. Journal of Applied Physics, 1977.

[3] Lehrbuch der Experimentalphysik: Bd.6 Festkörper. Ludwig Bergmann, Clemens Schaefer. De Gruyter, 2005.