Introduction

Ohm's law is usually assumed to be one of the simplest experimental laws in physics. The textbooks of general physics at the undergraduate level mainly deal with either its elementary consequences or with conduction models that can give an "explanation" of it. Careful discussions about the breakdowns of Ohm's law can be found in various places, but they are generally concerned with its failures at high frequencies, high values of the electric field and so on, and not with the compatibility of this equation with Maxwell's equations. On the other hand, most treatises on electricity and magnetism introduce Ohm's law in Maxwell's equations without adequate care[(1)] although some important consequences are deduced from it, like electromagnetic wave behaviour in conductors and the relaxation time for the dissipation of charge. There exist, indeed, some graduate level textbooks on electromagnetism[(2) (11)] that contain a deeper insight into the question; in these, it is generally assumed that the conductivity tensor σ depends on the magnetic field $\bar{B}$ and σ is expanded in powers of $\bar{B}$, thus obtaining a generalization of Ohm's law.
These approaches are clearly unsatisfactory from a modern point of view, since it is well known that a proper discussion of the conduction phenomena can be given only in a quantum-mechanical framework[(3)]; however, even from an elementary and non-quantum point of view some objections can be made to the treatments described above. Indeed, we will show that, introducing Ohm's law into Maxwell's equations leads to inconsistencies within the framework of

classical electromagnetism, while, on the other hand, a generalization of Ohm's law obtained assuming that the conductivity tensor σ depends on $\overline{B}$ and expanding it in powers of $\overline{B}$ is rather formal and obscures (expecially from a didactical point of view) the role of special relativity and of the Lorentz force; moreover, the coefficients of the series must be determined within the more difficult framework of a transport theory. Thus, expecially for didactical purposes, a non-quantum approach to conduction which neither leads to inconsistencies nor is purely formal seems desirable. Hence, we will also show that a generalized form of the conduction law can be deduced by making use of a slight generalization of the non-quantum conduction model which is often used to give an elementary microscopic interpretation of Ohm's law. This generalized law coincides, in the non relativistic limit, with the one that is usually found in solid state physics texts , and it avoids the above inconsistencies taking into account relativistic mechanics and the magnetic field (i.e. the Lorentz invariance of Maxwell's equations). Finally we will use this law to show that it implies some refinements of the concept of resistance (since the fields now influence the resistance) and that it allows a deeper understanding of the Hall effect, at least as far as the non-quantum electromagnetic theory of this effect is reliable.