INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

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GENERALIZATIONS OF CLASSICAL MECHANICS AND PLANCK'S OSCILLATORS

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INTERNATIONAL ATOMIC ENERGY AGENCY

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

1983 MIRAMARE-TRIESTE

IC/83/46

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization
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COMMENTS ON MICROSCOPIC MECHANICS, GENERALIZATIONS OF CLASSICAL MECHANICS AND PLANCK'S OSCILLATORS *

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ABSTRACT

The new microscopic mechanics removes the dichotomy of physics into classical and quantum phenomena. Its physical picture and connections with generalizations of classical mechanics are discussed. It gives a new meaning to Bohr's frequency relation and Planck's oscillators.

MIRAMARE - TRIESTE
May 1983

* To be submitted for publication.

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Many attempts exist in literature to understand quantum theory in terms of various "Hidden Variables". Apart from their successes and shortcomings, these attempts have at least some sound motivations which go beyond the "Copenhagen philosophy". The following quotation from Jammer [1] is a vivid description of this fact:

> "....... even the most "progressive"theoretician believes at the bottom of his heart in a strictly deterministic, objective world..... It explains why some physicists......tried to demonstrate that the existing theory.....is only a provisional approximation to a deeper scientific truth.
>
> .... Such a theory......would not only restore determinism and causality to the realm of microphysics, it would also dispense with the peculiar dichotomy of physics into classical and quantum phenomena and re-establish a unitary account of the physical world, a prospect of sometimes greater incitement than the desire for determinism".

Microscopic mechanics [2], while awaiting further development, goes a long way in removing the dichotomy of classical and quantum physics. In fact, it is also capable of refinement leading to a new level of physics where many deeper questions [3] of physics can be answered. However, here we discuss its connections with some known ideas and comment on them.

The equation of motion in microscopic mechanics [2]

$$\vec{F}_{ext} = \dot{\vec{P}} - \vec{f}_r \qquad (1)$$

has a familiar appearance for damped motions in Newtonian mechanics. It was recognized long ago [4] that an equation of this type could be connected with the Schrödinger equation. But there were two problems. The physical origin of $\vec{f}_r$ was not clear and some ad hoc hypotheses were made within the conceptual framework of classical mechanics. The second problem was the connection between $\dot{\vec{f}}_r$ and the Schrödinger wave function leading to an interpretation of the wave function. These ultimately remained unsolved and hence the approach was abandoned. There was a revival of interest in Eq.(1) through the work of Yussouff [5]. It was shown that $\vec{f}_r$ originates physically from the fact that every observable particle in nature is surrounded by fields. Therefore the usual concepts of Newtonian mechanics no longer hold good in microscopic mechanics. Only $\vec{F}_{ext}$ is the same [6] as the external force defined operationally in Newtonian mechanics.

The physical entity under consideration is analogous to the concept of a "dressed" particle in quantum field theory [7]. The motion of this particle and its own field under the action of an external force does not find adequate description in Newtonian mechanics. The behaviour of this physical system is sometimes radically different from that of a classical particle. Microscopic mechanics tells us that when an external force is applied the particle initially refuses to move due to the drag of its own field. Its inertia builds up [6] and after a certain limit, the motion takes place. As long as the energy taken up by the field far exceeds that taken up by the particle, there is wavelike behaviour leading to quantum phenomena. In the opposite limit, the particle aspect dominates and Newtonian mechanics holds good. In the intermediate regime it is the so-called "semiclassical" behaviour where perturbative corrections can be applied (analogous to the Larmor radiation formula in classical electrodynamics). There is a superficial similarity of these ideas with those vaguely put forward by Louis de Broglie [8].

The above considerations imply that $\vec{f}_r$ in Eq.(1) has to be treated differently from the usual damping forces in Newtonian mechanics. In particular, the various time derivatives of momentum, for example, in the expression for f_r in one dimension,

$$f_r = \left(1 - \frac{p^2}{m^2c^2}\right)^{1/2} \frac{\hbar^2}{8} \left[\frac{16m^2\dot{p}\ddot{p}}{p^5} - \frac{2m^2\dddot{p}}{p^4} - \frac{20m^2\dot{p}^3}{p^6}\right] \qquad (2)$$

have to be treated in a new way. A special characteristic feature of such a treatment is that f_r is maximum for p tending to zero and in the limiting process all the derivatives of p are related to p. This has a sound physical meaning [5]. In contrast, the time derivatives of p are completely independent of p in Newtonian mechanics. We note in passing that the independence of $\dot{p}$ in classical electrodynamics [9] makes the Abraham-Lorentz damping force,

$$f_{AL} = \frac{2}{3}\frac{e^2}{mc^2}\ddot{p} \qquad (3)$$

arbitrary and unbounded. Since it is independent of $\dot{p}$ and hence the applied external force, this damping force can cause motion on its own in the absence of any external force! That indeed is the "runaway" solution for the Abraham-Lorentz electron. No such thing is admissible in microscopic mechanics.

There is an important modification in the expression for f_r given by Eq.(2) when the mass renormalization changes considerably. Then the time variation of mass must appear in f_r. This is indeed so in view of the physical picture described above. Therefore the general form of the equation of motion in one dimension for non-relativistic case (neglecting p^2/m^2c^2 compared to unity) will be as follows:

$$F_{ext} = \dot{p} - \frac{p\dot{m}}{2m} + \frac{\hbar^2}{8}\left[\frac{2m\ddot{m}\dot{p}}{p^4} + \frac{4m\dot{m}\ddot{p}}{p^4} - \frac{11m\dot{m}\dot{p}^2}{p^5} + \frac{2m^2\dddot{p}}{p^4} - \frac{16m^2\dot{p}\ddot{p}}{p^5} + \frac{20m^2\dot{p}^3}{p^6}\right] \qquad (4)$$

This leads to a modified expression for energy:

$$E = \frac{p^2}{2m} + V + \frac{\hbar^2}{8}\left[\frac{2\dot{m}\dot{p}}{p^3} + \frac{2m\ddot{p}}{p^3} - \frac{5m\dot{p}^2}{p^4}\right] \qquad (5)$$

Again the connection with the Schrödinger equation can be established easily. By setting $\dot{m} = 0 = \ddot{m}$, one gets the equations used in the earlier work [2),5)]. There is also no significant change in the results or the physical picture used so far in microscopic mechanics except that the appearance of $\dot{m}$ and $\ddot{m}$ clearly indicate the variation of mass renormalization for very small p.

The inclusion of time derivatives of $\dot{p}$ in the equation of motion in microscopic mechanics has some similarities with attempts at the generalization of classical mechanics. One such attempt called generalized mechanics was due to Borneas [10] where the variational principle

$$\delta S = \delta \int_{t_1}^{t_2} dt\, L(t,\ldots,d_t^{(m)}q_k\ldots) = G(t_2) - G(t_1) \qquad (6)$$

was considered. The Lagrange function L contains up to the S^{th} time derivate $d_t^{(s)}q_k$ of the generalized co-ordinates. The corresponding Euler-Lagrange equations were obtained and the conservation laws were derived. Later on, the field-theoretical analogue of this procedure found its way into quantum field theory whence it was applied to some actual physical situations. But the mechanics formulation has remained almost without any physical realization and practical applications. The advent of microscopic mechanics is rather tempting in this sense and off-hand one might be inclined to identify it as a realization of generalized classical mechanics. However, a note of caution follows from the physical picture described above. It must be recognized that the various derivatives of p are related to each other in the limit of $p \to 0$ and this fact has not been incorporated into the generalized classical mechanics. A conenction between generalized classical mechanics and microscopic mechanics is possible only after the former is suitably modified.

Another interesting generalization of classical mechanics appears as the Birkhoffian generalization of Hamiltonian mechanics. Recently [11] the study of this mechanics involving non-potential interactions has been "quantized" to form the so-called "Hadronic mechanics". Writing Hamilton's equation in the covariant form

$$\omega_{\mu\nu}\,\dot{a}^{\nu} - \frac{\partial H(t,a)}{\partial a^{\mu}} = 0 \tag{7}$$

where $a^{\mu} = r^{\mu}$ for $\mu = 1,2,\ldots,n$, $a^{\mu} = p_{\mu}$ for $\mu = n+1,\ldots,2n$, and H is the Hamiltonian, the generalization leads to Birkhoff's equations (autonomous form)

$$\Omega_{\mu\nu}(a)\,\dot{a}^{\nu} - \frac{\partial B(a)}{\partial a^{\mu}} = 0 \quad . \tag{8}$$

Here $B(a)$ is the Birkhoffian. Then the Hamiltonian-Jacobi equation can be generalized to

$$\frac{\partial A^{g}}{\partial t} + B(t,a) = 0$$

$$R_{\mu}(a) = \frac{\partial A^{g}}{\partial a^{\mu}} \quad , \quad R_{\mu}(a_0) = -\frac{\partial A^{g}}{\partial a_0^{\mu}} \tag{9}$$

under generalized canonical transformation [11].

Now in microscopic mechanics one has the extended Hamilton-Jacobi equation whose eikonal approximation gives the Hamilton-Jacobi equations. Therefore it may be tempting to seek a connection between Birkhoffian generalization and microscopicmechanics. But the physical systems, the basic physical pictures and the initial conditions are entirely different in the two cases. Only the presence of a damping force (non-Newtonian or contact interactions with non-potential forces) can be a common feature. The formulation of hadronic mechanics is actually one step farther than envisaged in microscopic mechanics. It is the contention of microscopic mechanics that one needs no "quantization", once the correct equation of motion is written down and procedure for handling it are prescribed. Therefore the formulation of hadronic mechanics may be bypassed through a proper choice of the equation of motion within the framework of microscopic mechanics.

Our final comment here concerns the usefulness of the physical picture that emerges from microscopic mechanics. Several aspects of this physical picture have been discussed in earlier papers [2),5)]. Now we describe how it leads us to Planck's oscillators. In deriving the black body radiation formula, Planck had assumed the existence of oscillators which emitted and absorbed radiation in discrete quanta. Later developments of quantum theory led to the "picture" - if at all one can call it a "picture" - that the electrons in the atoms make transitions between discrete energy states (E_b to E_a) by "quantum jumps". Then a photon is "born" with energy $\hbar\omega$ and conservation of energy leads us to Bohr's frequency relation

$$E_b - E_a = \hbar\omega \quad . \tag{10}$$

Thus there are no oscillators although in the transition probability one employs the formula of density of states for "radiation oscillators" characterizing the radiation field. It is meaningless, in quantum theory, to enquire about the "motion" of the electron during "quantum jump" although the kinetic energies may be different in states E_b and E_a.

Microscopic mechanics yields Eq.(10) in a different way. The electron is held in a delicate balance in the ground state. When excited to a higher state, it behaves like an oscillator (small oscillation about a stable equilibrium) producing oscillating dipole moment. Then radiation is emitted and it returns to the ground state. Hence the transition between E_b and E_a levels also correspond to the energy difference between the ground state and an excited state of the oscillator which is $\hbar\omega$. There is no mystery about "quantum jump" and use of oscillator density of states. The oscillator frequency ω appears in the photon energy $\hbar\omega$ because microscopic mechanics leads to the usual equally spaced discrete oscillator levels. Thus the electrons actually behave as Planck's oscillators during absorption and emission of radiation.

In this paper, we have discussed the motivation, connections with generalizations of classical mechanics and usefulness of the picture of microscopic mechanics. From this, it appears reasonable to expect that further development of microscopic mechanics will make it practically useful and philosophically appealing unitary foundation of theoretical physics.

ACKNOWLEDGMENTS

The author would like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste.

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