Scientific Realism and Classical Physics

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Abstract

We recount the successful long career of classical physics, from Newton to Einstein, which was based on the philosophy of scientific realism. Special emphasis is given to the changing status and number of ontological entities and arguments for their necessity at any time. Newton, initially, began with (i) point particles, (ii) aether, (iii) absolute space and (iv) absolute time. The electromagnetic theory of Maxwell and Faraday introduced ‘fields’ as a new ontological entity not reducible to earlier ones. Their work also unified electricity, magnetism and optics. Repeated failure to observe the motion of earth through aether led Einstein to modify the Newtonian absolute space and time concepts to a fused Minkowski space-time and the removal of aether from basic ontological entities in his special theory of relativity. Later Einstein in his attempts to give a local theory of gravitation was led to further modify flat Minkowski space-time to the curved Riemannian space time. This reduced gravitational phenomenon to that of geometry of the space time. Space-time, matter and fields all became dynamical. We also abstract some general features of description of nature in classical physics and enquire whether these could be features of any scientific description?
1. **Introduction**

Realism has been the dominant ontology among the practicing scientist until at least the discovery of quantum mechanics in mid nineteen twentities. Indeed the origin of science among the ancient greeks itself depended on it. As Erwin Schrödinger, in his delightful Shearman lectures given at University College at London in 1948 and later printed as “Nature and Greeks”, emphasized that Greeks based their study of Nature on the following presuppositions:

(i) “the hypothesis that the display of Nature can be understood”, and

(ii) “the hypothesis of a real world around us”.

The first of these leads one away from arbitrary mythological way of thinking, and the second of these to the “objectivation of the world”. These are essentially the creed of scientific-realism.

The foundations of the classical physics, with which modern development of physics begins, at the end of the medieval world, were laid down by the great Isaac Newton (1642-1727).

2. **Newtonian Mechanics**

Newtonian mechanical view of the physics takes the matter in the world to consist of a number of “absolutely hard indestructible particles”, each endowed with a mass, moving on the stage of unchanging three-dimensional space with time under the action of mutual forces. He also discovered the “inverse square of the distance” law for the gravitational force between two bodies. The law was of an “action at a distance form”. This law of gravitation, together with Newtons three laws of dynamics, gave a remarkably accurate description of planetary motion. He thus laid the foundations of his system of the world in his magnum opus “Principia” (1687).

Newton also postulated an elastic medium “aether” to pervade the entire space and all the bodies contained theirin. It’s density was taken to be greatest in the interplatenatry space and variable in the various bodies. It was also, on the analogy of water vapour in the air, taken to contain various ‘aetherial spirits’, suitable to produce the phenomenon of electricity, magnetism and even gravitation.

Unlike Hooke and others who took light to be waves the medium ‘aether’, Newton rejected the conception of light as waves. His two main arguments for the rejection were (i) the propagation of light rays in straight lines, and (ii) the phenomenon of polarisation of light which he had observed. Another reason as to why Newton did not favour wave nature for light was his theory of colours arising out of his experiments on light refraction through glass.
prisms. They proved to him that different colours are already present in white light before it is incident and these are not produced due to it’s refraction. Hooke had regarded colours to be produced due to the effect of medium of wave propagation. This not being the case Newton rejected the Hooke’s wave hypothesis for light as well. The light for Newton thus had a corpuscular nature. The light and aether however affected each other.

When we observe the collision of two bodies on earth, we see a slowing down of the motion due either to inelasticity of the bodies or friction. Nowadays we attribute this to a conversion of mechanical energy to other forms of energy. But, in Newton’s time, such a principle of conservation of energy had not yet been formulated. So for Newton, another reason for the ‘aether’ was it’s need to avoid the slowing down of the observed planetary motions over long durations of time.

Thus Newtonian mechanics, with which classical physics begins, and which is one of it’s magnificent achievements, subscribes to realism. It’s ontology has (i) massive particles, (ii) space, (iii) time and (iv) aether as the basic real entities.

3. Wave theory of light

The observation of the burning power of convex glasses at their focus, however, suggested to Christiaan Huygens strongly that light must be basically a wave motion. The burning implies that light is associated with some kind of motion. In this experiment light beams moving in different direction do not obstruct each other in any way but are rather reinforcing in their effect which is possible with wave motion in a medium but unlikely for projectiles moving in different dimensions. He therefore came out strongly in favour of wave theory of light. He also made great advances in the mathematical theory of wave propagation. He reported all these researches to the French Academy in 1678. Light was now regarded as waves in the universal medium aether.

Further strong support for wave theory of light came in 1801 when Thomas Young explained “Newton’s rings” on the wave theory, and later using the same ideas the colours of thin films. He clearly formulated the general laws of interference of light waves and his “double slit” interference experiment is one of the celebrated experiments in history of physics. As interference phenomenon is not possible to understand on the corpuscular theory of light, it provides strong evidence for the wave theory. The mathematical treatment of diffraction of light, using wave theory was achieved by Auguste Jean Fresnel in his prize memoir submitted to French Academy in 1816. He did this by combining Huygen’s work with Young’s laws of interference.

The first tentative ideas that the polarisation of light is due to “the light waves being transverse” were given by Young in 1817 in his attempt to explain Fresnel and Arago’s experiments on interference of polarised light. Previously light was taken, in analogy to the sound waves, as longitudinal. Since only longitudinal waves are possible in a fluid, it
implied that aether must be an elastic solid. Fresnal, around 1821, tried to deduce dynamical consequences transverse waves for a solid aether.

After the work of Young, Fresnel, Arago and others the wave theory of light found general acceptance. The next great advance in the theory of light came from an apparently totally unrelated area of studies on electric and magnetic forces.

4. The Electromagnetic field

The earlier work on electrical and magnetic forces was modelled on “the action at a distance” Newtonian theory of gravitation. A drastic change of viewpoint took place with Michael Faraday. He discovered the law of electromagnetic induction in 1831. In trying to physically understand the electromagnetic induction, Faraday began to think in terms of “lines of magnetic forces”. These are the kind of curves in which iron filings arrange themselves around a magnet. He imagined the density of these lines of forces at any point in space to represent the strength of the magnetic intensity and their direction as its direction. He thus imagined the whole space around the magnet filled with a new entity “magnetic field” with a value and direction at every point. He had a similar conception of “electric field” among the space around any “electrically charged object”. We need not now regard the electric force between two distant charged particles as an “action at a distance”. Rather each particle is surrounded by an electric field and it is this electric field to which the other charged particles elsewhere respond. We thus have a “local interaction” theory of electrical, and similarly for magnetic forces.

Faraday did not express himself in mathematical language but as Maxwell perceived “his (Faraday) methods of conceiving the phenomenon was also mathematical one, though not exhibited in the conventional form of mathematical symbols”. Together with a novel concept, “displacement current”, a special flash of genius, Maxwell succeeded in distilling all the known laws of electricity and magnetism, into a coherent mathematical structure, “Maxwell’s equations” in 1864. What emerged was the unification of the concept of electric and magnetic into “electromagnetic field”.

One can now similarly conceive gravitational forces also arising from the local interactions via a gravitational field. Thus was added another class of ontological real entities “fields” to the classical physics.

An unexpected and remarkable fall out of the Maxwell’s work was the existence of waves of the electromagnetic field. The velocity of these waves, which was related to electric and magnetic polarisability of the “aether”, on being measured, was found to be numerically equal to the known “velocity of light” in space. Further they were transverse in nature. Maxwell then identified these electromagnetic waves with light. They were taken to be the waves in the same medium, named “luminiferous aether”, which was supportly responsible for electromagnetic fields.
5. The existence of atoms: A challenge to realism

John Dalton laid foundations of modern chemistry in 1808 through his system of a finite number of chemical elements. The indivisible constituents of these elements were their respective atoms. The molecules were taken as composed of these atoms of chemical elements. Amedeo Avogadro proposed in 1811, that equal volumes of any gas, under same pressure and temperature conditions, contain the same number of molecules. This number is now called Avogadro Number for a mol. of gas. To be meaningful this law implies that molecules really exist. In the nineteenth century most chemists used atoms and molecules as heuristic devices to bring order into the description of chemical reactions etc. They did not necessarily believe in their existence.

The development of kinetic theory of gases in the later half of nineteenth century, where the gases were regarded as a system of molecules in motion, took rapid strides. Clausius in 1857 identified heat as a form of molecular motion. Maxwell and Boltzmann proposed statistical mechanics methods to bring thermodynamical phenomenon under the domain of Newtonian mechanics. These efforts gave a big boost to atoms being regarded as real entities.

The entire evidence for atoms was indirect as they were not seen directly. They gave rise to first serious challenge to realism in classical physics. The great physical chemist William Ostwald, as well George Helm, regarded atoms to be just mathematical constructs. This is quite analogous to situation about quarks in mid twentieth century. Ernst Mach, in view of his positivistic philosophy, also doubted that atoms really exist.

This challenge to the reality of the atoms however was decisively settled in favour of their existence through the theoretical investigations on Brownian motion of small grains in the liquids carried by Albert Einstein in 1905 and their subsequent experimental verification by Jean Perrin in 1908-1913. Perrin measured the Avogadro Number in these investigation rather accurately. If you can count their number in a volume accurately, then the molecules must be real.

6. The motion of earth through aether

6.1 Galilean Relativity.

Newton’s three laws of motion are valid in a special set of reference frames ie ‘inertial frames of reference’. Newton’s first law says that a particle will keep moving in a straight line or remain at rest, if it is not acted upon by any external force. Clearly a particle which is moving in a straight line in an earth laboratory will not appear to be moving so if seen from another frame in which Sun, for example, is at rest due to diurnal rotation and the annual revolution around the Sun of the earth. It is therefore obvious that both the frames, geocentric and heliocentric ones, can not be inertial. We have to know, before using the Newton’s laws, if the frame in which we are applying them is inertial.
We first note a symmetry under transformation of space and time coordinates, called “Galilean relativity” of the Law’s of Newton. If they are valid in a frame of reference S then they are also valid in another frame of reference S’ which is moving uniformly in a straight line with respect to S. Thus if S is an inertial frame then so is the frame S’. This specifies the class of all equivalent inertial frames of reference provided we can identify one of these frames as inertial. In practice this frame can be taken as the frame in which the centre of mass of the solar system is at rest or has a uniform linear motion. Within accuracy required in the planetary calculation it could well be one in which the system of fixed stars is a rest or uniform linear motion. Galilean relativity also specifies the rules for transforming space and time, known as Galilean transformations from one frame to another frame of reference.

6.2 Maxwell’s electromagnetic theory of light and Galilean relativity

As long as Newton’s laws of motion are the only fundamental laws of nature, there is clearly no way to find the absolute velocity of any system of reference with respect to some absolutely fixed point at rest, in view of their invariance under Galilean relativity. The situation is drastically changed if we admit Maxwell’s equations for electromagnetic field, and light, to be fundamental as well.

Maxwell’s equations are not invariant under Galilean transformations. It is clearly seen by the fact that they predict the light velocity $c$ to be a fixed number. It can not be so in all inertial frames if they are related to each other by Galilean transformation. If the light velocity is $\vec{c}$ in its direction of propagation in the frame S it would be given by $(\vec{c} + \vec{v})$ in other frame S’ moving with respect to S with a velocity $\vec{v}$. The velocity of light is thus a fixed constant only in the frame in which luminiferous aether is at rest.

This clash of invariance of Newton’s laws and noninvariance of Maxwell’s equations opens up the possibility to measure the velocity of earth through the aether. A large number of experiments were devised for this purpose. However all of them were unable to reveal any motion of earth through the aether. Most accurate and well known of these experiments were those of Michelson and Morley in 1887.

6.3 Einstein’s special theory of relativity

This conundrum of nondetection of the earth velocity through the aether was attributed to possible dynamical effects such as Fitzgerald and Lorentz length contraction hypothesis ie all bodies shrink in length along their direction of motion by a certain factor depending on their velocity to light-velocity ratio, but remain unchanged in the other directions orthogonal to that of motion. Einstein however completely changed our way of looking at the problem through a revision of Newtonian concepts of absolute space and absolute terms. He reduced the problem to a change in kinematics.

In his revision of the classical concepts of space and time, Einstein’s central point of departure was his analysis of the concept of “simultaneity of two events”. Suppose we observe two events taking place in a particular fixed frame of reference, say a railway platform, then
there is no difficulty in saying whether they are simultaneous or not. However if the same
two events, which were simultaneous when viewed from the railway platform, are viewed
from another frame moving with a velocity, such that of a railway train or a linear track,
they would not appear simultaneous. This is because the light signals from the two events,
which are used to observe them, will take different times to arrive at the observer in the
moving train in view of finite speed of light signals. Since simultaneity is not an invariant
concept it follows that time can not be absolute.

As his guiding principle in finding the new concept of space and time Einstein held on
to the following two postulates:
1. The principle of relativity: All physical laws have the same form in all inertial frames i.e.
   frames of reference which move rectilinearly with a constant velocity with respect to each
   other.
2. The velocity of light is same in all inertial forms.

It was the crucial insight of Einstein to realise that while these “two postulates of special
relativity”, look irreconcilable, they are indeed not so. They appear so only if Newtonian
concepts of space and time are used. Indeed if they are modified, so as to accord with the
relativity of simultaneity, they can be reconciled. They then support a new structure of fused
space and time, called Minkowskian space-time, instead of a separate space and a separate
time continuums. It further follows that the two inertial frames are no longer connected by
Galilean transformations of space and time coordinates and time is not an invariant. They
are now related by Lorentz transformations.

A purely kinematic consequence of Lorentz transformations is the Fitzgerald-Lorentz
length contraction, which was postulated earlier in an ad-hoc way to explain the nonde-
tection of earth’s motion through aether. Another consequence is Einstein time dilation
according to which moving unstable particles such as pions live longer.

Maxwell’s equations turn out to be invariant under Lorentz transformations. Newtonian
laws of mechanics are however not so as they are invariant under Galilean transformations.
Einstein therefore proposed to modify them so as to make them also invariant under Lorentz
transformations. Since, for velocities small compared to velocity of light, the Lorentz trans-
formations reduce to Galilean transformation, the modified laws reduce to Newton’s Laws in
that limit. For higher velocities the expressions of the momentum and energy of a particle
to its velocity does change. A far reaching consequence is the Energy-mass equivalence.

It should be emphasised that as a result of special relativistic no signals using physical
particles, with a finite rest mass, can travel faster than the velocity of light.

6.4 The end of the “aether”

As both relativistic-mechanics of Einstein and Maxwell’s equations are invariant under
the same Lorentz transformation, the possibility of measuring the velocity of earth through
the aether is no longer there. Not only that now that the velocity of light in all inertial frames is the same there is no distinguished frame of reference, which hitherto was referred to that as that of luminiferous aether. We can thus dispense with the concept of aether on that score.

Another reason on which aether was felt necessary in classical physics was that it provided material substratum for the earliest “phenomenological” fields, such as mass-density and those corresponding to matter-velocity, temperature. All of these describe states of matter inside massive bodies. However to introduce these fields all over space and time it was felt that some thing, named aether, is there in the space even when massive matter is not present. This was especially so as ultimately all physical explanations were believed to be mechanical in nature. In fact originally Maxwell tried to reduce the electromagnetic fields also to a mechanism of pulleys and gears etc. but these attempts had to be given up as unsuccessful. It emerged that the concept of electromagnetic field necessitates that the fields are a new kind of ontological entity. The crutch of aether for imagining fields also gradually was not needed. Electromagnetic field could very well exist in space empty of matter.

As a result of the work on special theory of relativity the concept of aether became superfluous and was dropped from physics.

7. Gravitation and General Theory of Relativity

Further far reaching changes in our view of space-time, which is Minkowskian in special theory of relativity, and gravitation were still to come.

Newtonian theory of gravitation is an “action at a distance” theory in which the gravitational effects propagate instantaneously. This does not conform to the tenets of special relativity. It has to be therefore modified. Just as electromagnetic field is represented by vector field, the Newtonian gravitation can be represented by a scalar field. It is easy to write a Lorentz-invariant scalar field equation which would bring Newtonian theory in accord with special theory of relativity. This however did not satisfy Einstein.

It was known that the inertial mass of a body and it’s gravitational mass, ie the mass appearing in the force law of gravitation, are exactly equal. From this it follows that accelerations of a body due to gravity is independent of it’s nature. Since inertial mass on a body depends on its energy content, it is also independent of it’s energy. Since these facts have no natural explanation in the special theory of relativity. Einstein felt that to have a proper understanding of gravitation, one will have to generalise the special theory of relativity.

Now special theory of relativity still has a set of special frames of reference, called “inertial frames”, which are equivalent for describing nature. In fact Ernst Mach has asked the question as to why these frames are special. There was no satisfactory answer to this in special theory of relativity as there had been none in newtonian mechanics. In Nov. 1907, Einstein sitting at patent office in Bern, while preparing a review article on relativity,
had “the happiest thought of his life” that a person, in free fall, does not feel the force of gravity. He converted this insight into his “principle of equivalence” in 1911: the phenomenon happening in an uniformly accelerated laboratory are indistinguishable from those happening in a uniform gravitational field. Later it was generalised to more general gravitational fields. The final formulation of Einstein’s theory of gravitation, General theory of relativity, was achieved in 1915.

In General theory all the reference frames, connected to each other by differentiable coordinate transformations, are regarded as equally good for description of nature, thus addressing the concern of Mach. The laws of nature are thus form-invariant under such transformation and not just under Lorentz transformation. The space-time is no longer Minkowskian but curved Riemannian. The presence of matter causes space-time to develop curvature. The particles move in geodesics in this curved space time. The curvature effects of the space-time are equivalent to the gravitational force effects. The metric tensor of the Riemannian space-time is identified with gravitational field, which is now a symmetric second rank tensor and not a scalar. The principle of equivalence for general gravitational fields gets now reformulated as follows: The Riemannian space-time is locally transformable to a Minkowski one under coordinate transformations. The gravitational force is thus totally reduced to the geometry of space-time. With General relativity Einstein provided a fitting capstone to the beautiful edifice of classical physics. Space-time is no longer a passive stage on which matter plays it’s role, since matter and space-time react on each other, it is an active participant.

The general theory of relativity of Einstein is regarded as most beautiful theory of physics. The power of pure thought achieved so much with so little experimental input.

8. Some general features of World in the classical physics

Basing itself firmly on the rock of scientific-realism, classical physics has had a glorious career. The basic entities are point-particles, fields and space-time. All of these obey dynamical laws. The world of classical physics is deterministic. The role of probability is only to model complex situations as in Brownian motion and statistical mechanics so as to provide a useful simpler description. That determinism does not always lead to full predictability for all time was a discovery of Poincaré in his study of nonlinear chaotic systems.

The theories of classical physics are theories in which all interactions are local. This is so for Maxwell-Faraday electromagnetic interactions and Einstein’s theory of general relativity realised such a description for gravitation as well.

Another important and appealing feature of the classical physics is it’s unitary nature. All physical systems, whether those which are being measured, or those which are being used to measure, are described by the same classical physics. Within classical physics this point was so obvious that it was not even pointed out.
Whether these features of classical description of nature are peculiar to it or are they a deeper feature of any scientific description of nature? It may be tempting to answer the question raised with a ‘yes’, but a definitive answer, even about the validity of framework of scientific realism, is not yet in. As we know for atomic and radiation problems one had to develop, during 1900-1925, a new description, ‘Quantum Mechanics’ as classical physics proved inadequate for this task. The answer to the question raised depends on the problems of interpretation of quantum formalism, which is not settled yet. Depending on which interpretation we choose we get different answers.

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