The Paradigm of Projectile Motion and its Consequences for Special Relativity. Making Sense of Physics

Abstract

The classical (Newtonian) concept of projectile motion underwent a series of seemingly minor changes and adjustments between Planck's quantum discovery (1900) and Dirac's early codification of quantum theory (1928). The goal of physicists in this period was to keep change to a minimum and preserve as much as possible of the traditional projectile paradigm (TPP). These adjustments were successful in masking an all-out projectile paradigm crisis, but they have left us with a conceptual muddle. This has been especially deleterious for special relativity and our understanding of space contraction and time dilation.

1.0 Introduction

Modern concepts of projectile motion appeared in the seventeenth century through the efforts of Kepler, Galileo and Newton. Refinements came in the eighteenth century, e.g. the identification of inertia with Newton's first law. By the end of that century the traditional projectile paradigm (TPP) was set in place. There was no written codification of this paradigm, rather it was a set of assumptions, some of them implicit, that scientists ("natural philosophers") shared. These assumptions reflected common experience and they have not entirely disappeared in the twenty-first century. The main assumptions of the TPP are as follows.

A. The effective mass of a projectile is simply its inertial/gravitational mass, the two being equivalent.
B. Projectile velocity has but one "end point." That end point is zero velocity where the object ceases to be a projectile. There is no upper limit for an object's velocity.

C. Adding velocity to an object does not change that object.
D. Projectile motion features a material object traversing a set trajectory in space and time.
E. Projectiles have a mass quantity and a form (a shape). Projectile kinetic energy has no form, it is simply a quantity.

Between 1900 and 1928 physics saw the introduction of a host of new discoveries and concepts which would require some modifications of all the assumptions just listed. These paradigm modifications came incrementally and seemingly unconnected. There was no one thinker who oversaw the process and tried to see the changes as a whole; that is not how science works. Scientists work on specific problems (Thomas Kuhn's anomalies) and modifications they suggest are limited to their area of investigation and expertise. A century later we are able to survey the incremental changes as part of a larger whole; it is both revealing and enlightening.

Main arguments of this essay are as follows:

1. The changes to TPP in the years 1900 – 1928 were incremental and uncoordinated.
2. All scientists in this period were motivated to keep changes to the projectile paradigm to a minimum. To do otherwise was to lose the very foundation of scientific knowledge.
3. By keeping projectile paradigm changes incremental, scattered and unrelated, scientists (and philosophers of science) missed an opportunity to understand how projectile motion is a truly equal combination of mass with its form and energy with its form.

2.0 Changes Forced Upon TPP by the New Physics

2.1 A: — Effective Mass

Projectile inertia was solely a consequence of projectile mass accordingly to TPP. But by 1900 both theory and experiment indicated that projectile mass increased with velocity. Lorentz showed how this applied to the electron in his 1904 paper[1] and Einstein folded this concept into his theory of special relativity.

Consequences for TPP — Effective mass of the projectile had to be redefined to account for the projectile's kinetic energy. A distinction now had to be drawn between "intrinsic" (rest)

[1] H. A. Lorentz, "Electromagnetic Phenomena in a System Moving with Any Velocity Less than That of Light," *Proceedings of the Royal Academy of Amsterdam* 6 (1904):809-831.

mass and acquired (relativistic) mass. The classical concept of mass as exclusively a property of a material object now had to be revised. But it was fairly easy for TPP adherents to accept this redefinition of mass and still feel comfortable with the remaining projectile concepts.

2.2 B: — Projectile Endpoint

Lorentz transformation formulas defined relativistic mass in terms of rest mass and relative velocity: $m_{rel} = m_{rest}/\sqrt{1 - v^2/c^2}$. Relativistic mass increased without limit as v approached *c* and this made further acceleration progressively more difficult. As a consequence, no material object could achieve the velocity of light.

Consequences for TPP — Projectile motion now had an upper speed limit in addition to its known lower speed limit. A material object could not be a projectile unless it had a relative velocity greater than zero. And it could not be a projectile unless it had a relative velocity less than the speed of light. This speed limitation seemed fairly benign and engendered no obvious conflicts with TPP. Even approaching the speed of light in the period 1905 – 1928 seemed impossible to most physicists; the upper speed limit was a kind of theoretical limitation.

2.3 C: — Velocity Does Not Change an Object

Even before 1905, Lorentz and others argued that material clocks and rods might dilate and shrink, respectively, when progressing through an aether that supported electromagnetic radiation. Although Einstein's special relativity did away with the aether, the Lorentz transforms were still in effect. This meant that velocity caused material objects to shrink and clocks to run slow.

Consequences for TPP — Space contraction and time dilation for projectiles might be merely apparent (kinematics); on the other hand such changes might also be physical (dynamics). Either way TPP assumptions were called into question. A solution, or rather an approach, emerged in 1908 (Minkowski): treat relativistic effects as a subject separate from projectile motion. View an observer as occupying one inertial system with the projectile constituting a separate inertial system. Thought experiments and textbook explanations continue to follow this approach today, typically with an earthly observer measuring a remote spaceship via light signals. Relativistic effects are then associated with inertial systems and such effects become their own special topic separate from projectile motion.

2.4 D: — Projectiles Have a Set Trajectory

In 1923 Louis-Victor de Broglie proposed that quantized matter in motion had a wave identity just as quantized radiation had a particle identity. Einstein endorsed this concept and Schrödinger famously applied it to the hydrogen atom. Projectiles (including orbiting electrons) now had a wave identity in addition to their particle identity.

Consequences for TPP — If projectiles have a wave identity, how can they have a set trajectory? Fortunately, the wave identity only seemed to apply to particles of high energy and very low (rest) mass. Besides, Schrödinger's application of wave behavior was at the atomic level and it was uncommon to think of orbiting electrons as projectiles. Wave mechanics as a new area of inquiry seemed to be remote from projectile physics. Another part of projectile motion was broken off as a separate topic.

2.5 E: — Projectile Kinetic Energy has no Form

De Broglie's original argument associated a frequency with a particle's internal energy and with minimal justification he assigned this frequency to a wave accompanying the moving particle. Although the exact nature of this wave was and remains a mystery, physicists were not disposed to question de Broglie's arguments once experimental confirmation of particle wave behavior came in 1927.

Meanwhile, the concept of energy as a scalar physical quantity, defined only by its magnitude, had been firmly established for some decades. The great advances of thermo-dynamics indicated that energy was simply a quantity; by the 1920s all physics textbooks reflected that assumption. Physicists saw no reason to let go of that foundational truth because of "unrelated" discoveries in particle physics.

Consequences for TPP — There were no consequences for TPP. Once again, no connection was made between wave mechanics and projectile physics. Nor did the interdependence of particle waveform and particle energy suggest that kinetic energy itself might possess a form.

3.0 How Physicists Coped with Change

At this point the reader may object that TPP is not really comparable to those universally accepted paradigms that Thomas Kuhn examines such as the Ptolemaic view of the cosmos before Copernicus**.** Perhaps TPP is but one part of the larger Newtonian paradigm that was being chipped away

after 1900. In any case it is certainly true that physicists in the year 1900 would have accepted without debate the assertions A through E cited above. By 1928 all of those assertions (with the possible exception of E) had been shown to be either flawed or false.

The actual process of replacing the Newtonian paradigm in the early decades of the twentieth century was neither easy nor simple. As Kuhn has noted[2] scientists seek to minimize change and confine it to their narrow sub-specialty. Sometimes they invent ad hoc additions to account for new discoveries. But as we have seen with projectile physics, they have another stratagem for limiting change: break a general field of inquiry into lesser sub-fields the contents of which now seem unrelated to the general field itself. Thus electron motion around a nucleus became its own sub-field entirely divorced from projectile motion. Einstein himself created a sub-field when he introduced special relativity although it was Minkowski who pushed this to its logical conclusion.

Minkowski took Einstein's space and time and unified them into a four-dimensional geometry wherein different observers (inertial systems) were represented graphically by different world lines. These world lines (observers) differed by their (relative) velocities; the fact that velocity difference meant kinetic energy difference was now ignored. The graphical world lines were now distinguished by relative velocity and not by relative kinetic energy. As a consequence, velocity itself somehow had be the explanans for space contraction and time dilation.

The piecemeal changes to TPP plus the tendency to split up projectile physics into sub-specialties put physicists at a disadvantage in the years 1900 – 1928. They were unable to see how the new ideas and discoveries were interrelated. A century later we can see that much of the "new physics" was really a more complete description of projectile motion, especially of the role played by projectile kinetic energy. Rather than the bit by bit, ad hoc accommodations made to TPP, we are now, a century removed, able to see that most of the changes had their origin in the equality of mass and energy at a foundational level. A more logical and cohesive explanation of projectile motion, and therefore of special relativity, is now possible.

4.0 Projectile Wave Identity

In Newtonian physics stationary mass and projectile mass had mass and shape in common, but nothing else. Since "shape" is a term of geometry rather than of physics, we need an alternative term. Material objects extend in space and have a quantitative mass measure; therefore we may characterize

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[2] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Univ. of Chicago Press, 3rd edition, 1996) p. 78

such objects as constituting a (density) field. “Field” here is used in the simple sense of mass or stored energy extending over space; examples would be a material object occupying space or the electrostatic field surrounding an electron or an ion. Field form extending over space (as a volume) is the opposite of waveform oscillation extending over time (as an interval). Both feature something physical – mass or energy – extending over a dimension.

By 1928 physicists knew that projectile velocity had an upper limit as well as a lower limit and that mass and energy were equivalent ($E = mc^2$). They also knew that because of mass-energy equivalence projectile kinetic energy created relativistic mass; the increase of kinetic energy meant the proportional increase of relativistic mass. At the time these new facts seemed benign in their relation to accepted concepts, but in fact they pointed to a whole new interpretation of projectiles.

These new facts indicated that projectiles occupy a middle ground between two extremes: space-stationary mass (stationary for a local observer) on the one hand and the time-stationary photon on the other. Projectiles approaching either extreme resemble that extreme. Slow moving projectiles resemble the field-form stationary material object; projectiles approaching the speed of light resemble the waveform photon. The waveform of fast projectiles is a consequence of their kinetic energy dominating their rest mass. Projectiles are a combination of rest mass and kinetic energy and the relative proportion of one to the other determines whether field form or waveform dominates.

The first laboratory confirmation of de Broglie’s matter waves came in 1926/27 with Davisson’s and Germer’s experiments on high speed diffracting electrons. Wave behavior then (and now) became inextricably linked with diffraction effects. But the idea that only particles of tiny mass (and high energy) have a wave character is quite wrong. Of course the larger the projectile’s mass the shorter its wavelength since an object’s momentum is inversely proportional to the wavelength λ of an object: $\lambda = h/mv$. This means that large objects at high velocity (meter sticks, spaceships) can never diffract, but they still generate the same de Broglie wave character as a much smaller mass at the same velocity. The wave identity of a high speed projectile is always present regardless of projectile mass.[3] Does this wave identity have any connection to the space contraction and time dilation that is part of special relativity?

By equating wave identity with the diffraction of subatomic particles, physicists have overlooked the connection between any projectile’s wave identity and dimensional warpage (space contraction,

[3] The wave packet of the large projectile is well-defined in space; not so for the very small projectile.

time dilation). Explicating the connection between wave identity and dimensional warpage requires a closer examination of projectile progression and extension

5.0 Progression versus Extension

Inertial mass is space stationary for a local observer; it lacks any kinetic energy and we may characterize it as "pure mass." The photon is time stationary by its own measure and since it lacks any rest mass we may characterize it as "pure energy." Between these two extremes lie projectiles which combine both rest mass and kinetic energy in varying proportions.

Pure (inertial, space-stationary) mass extends in space but progresses in time (the arrow of time). Pure energy (the photon) extends in time (its oscillation cycle) and progresses in space (the arrow of space). This means that any pure entity extends in one dimension only and progresses in the other. Pure mass does not extend in time, it progresses there; being space-stationary it does not progress in space, it extends there. Similarly with the photon: it extends only in time and progresses only in space.

However, projectiles combine field form mass and waveform energy (de Broglie waves) and there is a fundamental opposition between them regarding space extension. The field form of the projectile (defined by its rest mass) extends in space. But the waveform of the projectile has zero extension in space since it only progresses there (think of electromagnetic radiation waves which have no space extension, only space progression).

A projectile is not simply rest mass translating in space. A projectile is a combination (union) of rest mass plus kinetic energy that creates a hybrid entity different from space-stationary rest mass. Projectiles as hybrid entities combine rest mass extending in space with kinetic (wave) energy **NOT** extending in space and the result is contraction of the hybrid entity's space extension.

Our common experience with material objects makes it very difficult to imagine why such objects – absent some stress from an aether – should space contract in the direction of motion. But we have to remember that material objects have a form and it is their field form that defines their space extension. Projectiles combine both waveform and field form and when projectiles move at extreme velocities relative to an observer then the waveform dominates that projectile for that observer. In this case the field form of the projectile's intrinsic (rest) mass has faded in intensity and diminished in spatial extension because a projectile's form is singular even though it is a mix of wave and field.

All of the entities that are of interest to physicists – space-stationary matter, time-stationary photons, projectiles – have but a single form. The two non-projectile entities have a purity of form: either pure field form for matter or pure waveform for the photon. But for projectiles their single form is

a mix of field form and wave form. The characteristics of one pure form (e.g., extension in space, progression in time) may be overlaid and diminished when combined with the opposing characteristics of a different pure form (e.g., progression in space, extension in time). When mass and energy combine to create a new, observer-relative entity (projectile), it is the form of that new entity which determines dimensional extension and progression. Space contraction and time dilation of material objects (rods, clocks) in motion are direct consequences of the dominance of waveform over field form.

Forms have an ontological, not a Platonic, significance. The field form of a projectile is an expression of the existing nature of that projectile (due to rest mass). The waveform of a projectile is an expression of the occurring nature of that projectile (due to kinetic energy). Existence and occurrence, field form and waveform, and progression in a dimension versus extension in that dimension: all are facets of the single ontological reality that constitutes a projectile.

Space contraction is objective but it is also observer dependent. Different observers at different relative velocities encounter different space contractions for what they regard as the same object but which in fact are different hybrid entities with different mixes of mass and kinetic energy and hence different forms. An observer accompanying the projectile experiences no space contraction because the rest mass is no longer a projectile.

Time dilation follows a similar pattern. The rest mass of a projectile as a material field progresses (races along) in time, but the kinetic energy of a projectile as a radiation wave does **NOT** progress in time. Radiation waves, either de Broglie or electromagnetic, progress only in space; they are stationary in time and extend there. The combination (union) of a rest-mass field's finite time progression with an energy wave's zero time progression yields a slower (dilated) time measure for the projectile as measured by an at-rest observer.

Inertial observers with different velocities relative to a common material object (projectile) are each encountering a different blend of rest mass and kinetic energy, of field form and waveform, and consequently a different (hybrid) entity. Since these different observers measure different entities, of course they find different splits between wave and field, between time and space and between rest mass and relativistic mass.

6.0 Physics Theories

All explanations in physics are theories. Some theories have near universal acceptance, an example being the kinetic theory of gases. Other theories generate debate and rejection by some. As

Kuhn has pointed out,[4] scientists are partial to ad hoc explanations for phenomena not well understood (anomalies) lest an entire paradigm be called into question. Physics is the study of mass and energy, with energy understood broadly to include forces such as gravity and magnetism. Conventional causal agents usually involve mass but always require energy. We should be very skeptical of unconventional causal agents that bypass mass and energy or presume an unknowable entity.

Lorentz's theory of space contraction and time dilation has the aether as a causal agent and while the aether purports to be material (with some fantastic properties) it remains undetectable and unmeasurable. Minkowski too invokes something undetectable, but in his case something immaterial. Minkowski posits a substantivalist spacetime reality of four dimensions that can never known directly since human observers can only access the shadows of this reality, namely separate space and separate time.[5] In both cases these causal agents are buttressed by impressive mathematics. But both of these theories, developed for a specific physics anomaly, depend upon unconventional causal agents and both merit our skepticism. Both betray their time of origin, namely early in the relativity revolution before de Broglie and before the depth and extent of the equality of mass and energy ($E = mc^2$) was fully understood.

The ideas presented in these pages are also a theory of space contraction and time dilation. But this theory is grounded upon known features of mass and energy. De Broglie waves have been demonstrated in the laboratory for tiny masses and the fact that they also obtain for large objects is beyond question.[6] That a rest mass has extension in space is obvious. That radiation waves (de Broglie or electromagnetic) have zero extension in space may be unfamiliar to many but should be obvious upon reflection. The conceptual equivalent of the latter is the truism that rest mass does not extend over (occupy) a time interval.

De Broglie waves depend upon kinetic energy and are objectively real. Proposition C above (Section 1.0) is false; velocity, or rather kinetic energy, does change projectiles and they are not merely rest mass translated without change over space. Projectiles are an observer-relative, objective union of

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[4] Kuhn, p. 78.

[5] "Henceforth, space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." Minkowski, 1908.

[6] In terms of rest mass for speeding projectiles, as you move up from an electron to an atom to a large rock to a spaceship there is no rest mass magnitude cut off point you can cite where the de Broglie wave identity ceases to apply. The de Broglie wavelength formula ($\lambda = hc/pc$ where h is Planck's constant and p is momentum) works downscale as well as upscale since it yields the wavelength of the photon.

field form rest mass and waveform kinetic energy resulting in a hybrid entity (and a single mixed form) unimaginable in classical physics.

7.0 Conclusion

Physicists of the 1900 – 1928 era were very smart men, some of them geniuses. But as recounted, new discoveries, anomalies, breakthroughs and theories came piecemeal and fast in no logical order. It was impossible for any participant, however smart or wise, to fully rise above the intellectual chaos and controversy of those decades. Whenever possible they either clung to traditional ideas (kinetic energy as quantity) or assigned new ideas (e.g., matter waves) to a separate physics sub-category for specialists. They regarded projectile kinetic energy, matter waves and dimensional warpage (contraction, dilation) as unrelated phenomena. Inevitably they overlooked connections between these phenomena and they missed a chance for a fresh definition of some of the foundations of physics. One of those foundations was the role of energy along with mass in projectile motion.

References

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