

The Arrow of Time

Kieran Hobden

Notes Abstract: Topics of microscopic reversability, macroscopic invariance, information
Modern theories are

Consider ball going up and down Velocities appear reversed in time reversal yet acceleration is the same Inconsistency of Newtonian mechanics and electrodynamics —; Special Relativity! :O Non-holonomic constraints?? e.g. bikes???

1 Introduction

What is ThERmoDYnAmiCS?

2 Newtonian Mechanics and Time Reversability

The Newtonian picture of the world, although known to not be an entirely correct view of the world, is a good place to start when considering the symmetries of time due to its simplicity. All processes in this picture are seen to be time-reversal symmetric: a ball, for example, thrown upwards such that its trajectory is a parabolic arc could be filmed and the video, run in reverse, would appear to be as likely to have occurred as the original footage. This is a common starting point for discussing time-reversal symmetries. We start by saying that a process is time-reversal symmetric if the process run in reverse (under the transformation $T : t \longrightarrow -t$) is a legitimate process according to the laws of the governing theory. In this way, all processes in the Newtonian picture of the world seem to be time-reversal symmetric. A video of a billiard ball on a frictionless table which knocks into another, setting both balls on new trajectories could be reversed and the situation would look as believable as if it had occurred running forwards in time. This is due to the microscopic reversibility of Newtonian mechanics. Unfortunately, by discussing the motion of billiard balls and other macroscopic processes, we have taken a foray into the one of the simplest violators of time reversibility: friction. Imagine a book slides along a surface. The book will be seen to have some initial velocity which is reduced parabolically until the object is stationary. If this process were filmed and viewed backwards, it would appear non-sensical that an object might go from being stationary to having its velocity increase parabolically. This clearly violates Newton's First Law and therefore shows no time-reversal symmetry.

Before we get ahead of ourselves, we must take a more exact description of the necessary conditions for a process to be time-reversal symmetric. If we suppose that there is some fundamental theory of the world, T , any process can then be described as a sequence of instantaneous events, S_i, \dots, S_f . Then the requirement for the process to happen backwards is simply that the sequence S_i, \dots, S_f must also occur in T .

But how can we know the sequence of instantaneous conditions? Suppose we had a system which was sufficiently small such that we could gather and store all the information we needed to fully define the system (remembering that absolute positions and velocities are possible as we are still in a Newtonian picture and quantum effects are not present). The causal nature of Newtonian mechanics would allow us to determine the later instantaneous conditions in the sequence S_i, \dots, S_f thus we would be able to determine the full sequence from the initial condition.

However, a complete, instantaneous description of the world is not sufficient in the Newtonian picture as the positions and velocities of all particles in the universe (along with non-dynamical properties such as mass and charge) are necessary. The positions and velocities of all the particles in the world at any one instant are not independent of their positions and velocities at other instants therefore this description of the world is not that of an instantaneous state. Consider now a sequence of dynamical states D_i, \dots, D_f which fully describe the Newtonian picture of the world. If this sequence describes a particle moving to the left, then its reverse should logically describe the particle moving to the right if the theory is time-reversal symmetric. However, the sequence D_i, \dots, D_f (the reverse of the original) would describe the particle moving to the left with its velocity vector pointing to the right which is non-sensical. This suggests that something more complex is required to reverse

time than simply the events run in reverse. In this example we must invert the dynamical conditions such that the velocity vector points in the opposite direction. This idea is specific but can be generalised. A sequence of dynamical conditions D_i, \dots, D_f must be translated to a sequence of instantaneous states such that they can be reversed. If the Newtonian picture simply requires that the velocity direction is reversed then the commonsensical sequence of instantaneous states S_i, \dots, S_f that we originally used, in reverse, amount to the same as the set of transformed dynamical conditions in reverse such that the more simple sequence can be used (although slightly incorrectly) to describe the Newtonian picture of the world.

So, can this time-reversal symmetry ever be violated in the Newtonian picture? Suppose we have a video recording of a ball that is rolled up the side of a dome with just enough energy such that the ball reaches the pinnacle of the dome but rather than overshooting or rolling back down, the ball remains stationary. Now, if we watch the film in reverse, the ball appears to go from being stationary to accelerating for an extended period and seemingly violating Newton's First Law of Motion. Naturally, due to quantum fluctuations the ball will inevitably roll back down the dome eventually but in the Newtonian picture of the world this is not relevant, and we expect the ball to remain in position. This highlights our inability to use physical intuition in this scenario. John D. Norton highlighted this problem in his 2003 paper: *Causation as Folk Science*. He proposed that this apparent contradiction to time-reversal symmetry is not an issue for several reasons. Firstly, that a ball placed on top of a dome cannot show a preference as to whether it remains or rolls down the side of the dome. It is not just a lack of preference but furthermore, the system produces no probabilities to distinguish which outcome is favourable. It is often suggested that this is because it is impossible for the ball to roll back down due to Newton's First Law of Motion which brings us on to Norton's next argument. He argued that the law: "In the absence of a net external force, a body remains at rest or in a state of uniform motion in a straight line." Should be altered to "In the absence of a net external force, a body is unaccelerated." Norton then provides the equation for the acceleration of the ball and shows that at time $t = T$ (when the ball appears to first move), the acceleration is zero which satisfies Newton's First Law. My personal objection arises due to Norton's re-statement of the law. I have previously stated that a complete description of the Newtonian picture of the world requires the dynamical conditions: position and velocity. However, Norton requires the law to be instantaneous before using it to describe dynamical conditions. BUT AM I SURE? NO! I'M DUMB AND CONFUSED! Another objection might arise from the fact that the ball never actually reaches the pinnacle of the dome. It simply takes a progressively longer time to make progressively smaller movements up the dome such that it never actually reaches an unstable equilibrium where it is stationary. This means that the acceleration on the ball is never zero and therefore the time-reversal of the motion would appear perfectly legitimate in the Newtonian picture. However, if we suppose that the ball could be placed exactly at the point of unstable equilibrium then might it spontaneously slide down the dome? Unfortunately, we can gain no further insight into this approach as the time-reverse is simply the ball being picked just as it was placed beforehand. It should be noted that this situation is in no way special and the analysis can be applied to other systems whereby an object reaches a point of unstable equilibrium with no local stable equilibrium.

If we assume however that Norton was correct and that the ball, in an unstable equilibrium, would roll back down the slope (note this is not verifiable from the real world as it

is non-Newtonian), then we enter the possibility that the dynamical world might require an instantaneous description under observation similar to that of quantum mechanics. Perhaps quantum mechanics provides the mapping for the dynamical conditions of the world to an instantaneous set such that time-reversal is possible?

2.1 What does it mean to be reversible?

For a theory to be time-symmetric, we expect to observe the same results if time is running forwards or backwards.

If the theory predicts the f

2.2 Equivalence of Statements

2.3 Planck's Proposition and Perpetual Motion of the Second Kind

3 Entropy and the Arrow of Time

It is well known that time has a specific direction; the past is unchangeable and we are left with only memories, whilst the future is not yet determined and we can have no understanding of the future until it arises. This intuitive arrow of time allows us to distinguish whether a video of a burning fire is played in reverse and is our natural interpretation of entropy and the laws of thermodynamics.

Mention time asymmetry of only the 2nd law

3.1 Principle of Microscopic Reversability

3.2 Loschmidt's Paradox

In 1876, Johannn Josef Loschmidt argued that it should not be possible

4 Information Theory

5 Uses of the Second Law in the Explanation of Natural Phenomena

5.1 Brownian Motion

5.2 Osmosis

6 Appendix

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