One, Two, Three… Relativity: The Universe of Albert Einstein

University of Richmond Osher Course – Winter-Spring Semester, 2026

James Miller – Class Leader Email: solargd@gmail.com

The first thirty years of the twentieth century produced a revolution in physics the likes of which have not been seen before or since. At the center of this revolution was Albert Einsten, not only for his theories of relativity but also as one of the founders of quantum theory. The course explores the foundations of our modern view of the universe and the major scientific personalities of the time.

A copy of the course slides in PDF format will be available for download on the website www.dracorex.com/osher.

BACKGROUND INFORMATION AND KEY CONCEPTS

Physics is the study of matter and energy, the most fundamental of all sciences.

In this course we focus on two ideas of theoretical physics that were introduced during the first thirty years of the twentieth century—the theories of relativity and quantum theory. These ideas turned out to be the most revolutionary in the history of science, drastically changing forever humanity's view of the universe. At their core are concepts that defy common sense. For example, the flow of time can slow down or speed up, no material body can be accelerated to a speed equal to that of light, space is not a void but has structure that can be bent and warped, a particle can appear to be in two places at the same time, 'entangled subatomic particles can instantly communicate with each other even when separated by vast distances, and reality may not exist until one looks for it.

Warning! Many of you may feel frustrated at attempting to 'understand' some of the material presented in this class. Do not be troubled. It's not you. To quote the Nobel Laureate Richard Feyman, "I think I can safely say that nobody understands quantum mechanics …"

The Scientific Method

- The foundation of science is measurement (data), derived either by observation or from experiment.
- If you can't measure it, it's not science.
- Scientific theories are attempts to makes some sense of the measurements by proposing relationships between measured quantities.
- A theory is only 'scientific' if it is falsifiable.

Velocity and Acceleration

The concepts of **velocity** and **acceleration** play an important part in our story.

A thing accelerates when its velocity changes, that is, speeds up, slows down, or changes direction. The difference between moving at a constant velocity and accelerating is that when the latter occurs, your body behaves as if a force is being exerted on it.

For example, you are the passenger in the front seat of an automobile sipping your morning coffee. Everything is fine as long as the automobile is moving at a constant velocity (speed). You experience no sense of motion. As far as drinking your coffee is concerned, it is as if you are not moving at all.

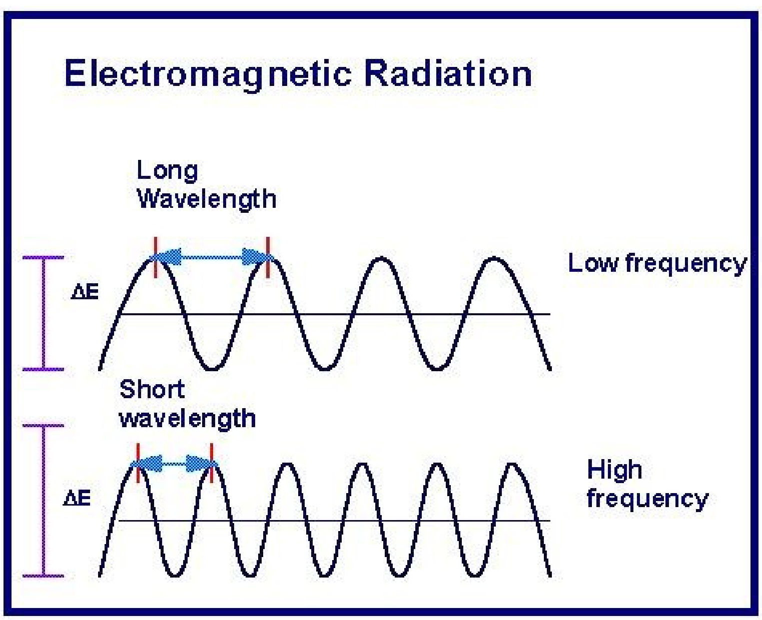
- The driver steps on the gas pedal, you feel a force pushing you back into the seat and you are splashed with coffee.
- The driver slams on the brakes. Your body flies forward but is fortunately restrained by your seatbelt preventing you from crashing into the windshield. Coffee flies everywhere.
- The driver makes a hard right turn. Your body is jerked to the left and the driver is drenched in coffee.

Light (Electromagnetic Radiation)

A photon (particle of light) is characterized by a wavelength λ and frequency ν. All photons travel at the speed of light, c. The speed of light is equal to the product of the photon's wavelength and frequency, that is,

$$c = \lambda\nu$$

The higher the frequency (and thereby the shorter the wavelength), the greater the energy of the photon.



The electromagnetic radiation with the lowest energy (that is, longest wavelengths) are radio waves. Those with the highest energy are X-rays and gamma rays (their energies overlap). What distinguishes an X-ray photon from a gamma ray photon is how they are created.

Time and Space

In our everyday experience, we tend to think of units of time as being fixed in stone; for example, a second for someone living in Richmond is the same as a second for an astronaut who has landed on the moon. We also tend to think of the vacuum of outer space as being the absence of stuff; that is, it contains no atoms. It has no form or structure. Albert Einstein shocked the world by proposing through his two theories of relativity that these perceptions are false.

The two theories of relativity are differentiated as a ‘special’ theory and a ‘general’ theory. The essence of each theory with regard to time and space is as follows.

Special Theory of Relativity – time can be stretched and distorted; the passage of time can be different for different observers.

General Theory of Relativity – both time and space can be stretched and distorted by the presence of mass which ‘explains’ the force of gravity.

What about the most famous equation of all, $E = mc^2$? It’s a product of the Special Theory. The General Theory deals with gravity.

Glossary

Inertial frame (also ‘inertial frame of reference’) – It’s jargon for moving at a constant velocity, that is, unaccelerated motion. You find this term used in just about any explanation of the theories of relativity. Things are complicated enough without jargon. Instead of referring to an inertial frame of reference, the presenter will simply state that something is moving at a constant speed with no change in direction.

Electromagnetic radiation – Another term for *light*. Light is not only what we can see (i.e., ‘visible light’) but also includes (from lower energy to higher energy) radio waves, microwaves, infrared light, ultraviolet light, gamma rays and X-rays.

Photon – A small packet or quantum of electromagnetic energy—that is, a particle of light.

Wave-particle duality -- The concept that light (i.e., a photon) can behave both like a particle (i.e., a tiny solid object) and a wave (like rippling water) depending on how one observes it.

Superposition – The concept that quantum particles can exist in multiple states simultaneously, at least until observed. An analogy would be a spinning coin in the air—it’s neither heads nor tails until it lands. The Schrodinger’s cat thought experiment attempts to illustrate this concept.

Entanglement – The state where two quantum particles become linked so that the observation of the state of one instantly affects the state of the other, regardless of the distance separating them.

Heisenberg’s uncertainty principle – One can’t measure both the exact location and speed of a quantum particle at the same time. It’s either one or the other. Your choice.

Cosmological redshift – The observation that the wavelengths of light from distant galaxies are shifted towards higher values (e.g., the wavelength of visible light is shifted towards the red end of the spectrum). The most popular explanation of the redshift is that it is evidence for an ‘expanding’ universe.

Further Reading

Thirty Years That Shook Physics, George Gamow, 1966. Although parts of it can get a little deep—i.e., math, it also contains numerous eyewitness insights on the scientific giants of the era by one who was there.

Relativity Simply Explained, Martin Gardner, 1997.

Schrodinger’s Kittens and the Search for Reality: Solving the Quantum Mysteries, John Gribbin, 1996.

Six Impossible Things: The Mystery of the Quantum World, John Gribbin, 2025.

Search the Khan Academy video library for instructive presentations on relativity, quantum theory and the expanding universe.