



PHYSICS SUMMER SCHOOL 2012

Day 1:

Classical Mechanics

We will begin the summer school by looking at various elements of classical mechanics. We will trace the historical development of classical mechanics, paying particular attention to Newton's Laws and the theoretical developments of 17th century "natural philosophers". We will examine three core concepts of classical mechanics: force, motion in a straight line, and uniform circular motion. The laws that govern these motions have, for hundreds of years, explained how and why objects move. But do these laws always hold?

Quantum Mechanics

Students will examine the historical development of quantum physics and will learn how classical mechanics breaks down at atomic and subatomic levels. We will examine wave-particle duality, which is the idea that on a quantum scale all particles exhibit the qualities of both waves and particles (contrary to the classical model in which particles only exhibit particle-like qualities). We will also examine the uncertainty principle, which shows that at the quantum level it is impossible to simultaneously know position and momentum, and we will discuss wave functions and the Schrödinger's equation. Students will also get to put their mathematics to work as we will be learning abstract mathematical expressions of quantum physics. We will also be examining the fascinating philosophical problems that arise out of quantum: is the universe not causally determined after all? If there is no cause do we live in a state of constant randomness? Can multiple equally real worlds exist simultaneously? Has quantum undermined or enhanced our knowledge of the physical universe and our place in it?

Day 2:

Special Relativity

In this section we will discuss the historical development of special relativity and we will continue our discussion of how and why classical Newtonian physics breaks down. We will discuss the idea of motion and how when we accelerate motion to a speed approaching the speed of light we end up with the conundrum of relativity. One key idea that emerges is that we should stop thinking about time as somehow 'separate' from the three spatial dimensions, and instead think of all four as coming together in what is known as 'spacetime'. This brings with it several seemingly bizarre results, including the idea that time appears to slow down and that objects contract when they are moving with high



speed. These phenomena are explained as time dilation and length contraction and they are ideas that students will battle with on this course.

In addition to accounting for a great deal of very bizarre phenomena, special relativity says that mass and energy are equivalent, through the famous relation $E = mc^2$. This means that we are able to convert energy into new particles (for example, in particle physics experiments) and also that we can 'unlock' the power stored in the mass of atomic nuclei for use in generating energy. This course explains how, based on two simple postulates, Einstein's theory totally revolutionised the way in which scientists grasp the simple concepts of space, time, energy and momentum into a theory that was consistent with the experiments being performed at the start of the last century. In this course we will begin by looking at some of the experiments that pre-dated Einstein's work, including the Michelson-Morely experiment, which was the first experiment ever done that supported a theory of relativity. We will also look at Lorentz transformations, which express time and space as basic coordinates. The Lorentz equations that are derived from these coordinates are particularly interesting for they were later re-appropriated by Einstein to help prove his theory of relativity. Finally, we will discuss how Einstein's theory of special relativity relates to particle physics.

General Relativity

General relativity is Einstein's theory that gravity is best described as a geometrical property of space and time whereby space and time are intricately woven together creating a four-dimensional reality: spacetime. Einstein's theory of general relativity underlies our understanding of gravitational waves, the density of stars, x-ray sources, various masses within our universe and indeed even big bang theory and the evolution of our entire universe. It is also general relativity that leads us to believe in the existence of black holes: masses in the universe that are so dense that they can bend space-time and thereby prevent the passing of light.

In this unit students will examine Riemannian geometry, which enables Einstein's theory of general relativity; the Newtonian Limit, at which spacetime approximates flatness; and Einstein's equivalence theory, which states that "it is only when there is numerical equality between the inertial and gravitational mass that the acceleration is independent of the nature of the body". Students will also examine Einstein's three tests for general relativity as well as contemporary experimental tests into general relativity such as ones currently being conducted by NASA.

Day 3:

Particle Physics

This session involves an outline of the key concepts of particle physics, from Wavefields to Quantum Physics, as well as an overview of the history of particle physics from Democritus



to Dalton. Students will examine the Rutherford experiment, which determined the structure of an atom, and they will look at Bohr's work on the nature and structure of the atom, which formed the very basis of quantum and particle physics. In order to understand the constants and variables we utilise in particles equations and inductions, students first need to grasp the origins of these factors and the limitations of them, as recognised by those who first hypothesised them.

Students will then examine the standard model of particle physics by looking what the universe is made of, how matter interacts, and how new particles are created. We will then be taking a look at the work of the Large Hadron Collider (LHC) at CERN. The project has numerous aims, but overall is an effort to better understand the laws and forces of nature. In particular we will be examining effects on the standard model for the analysis of atoms as well as flaws that exist within our understanding of the model as a result of using high-energy particle experiments. This project is at the forefront of modern developments in physics. As a result this session gives students an insight into the future of study in the area of particle physics. The conclusion of the material on particle physics examines the ever-elusive "God Particle", the Higgs Boson which is theorised to bestow mass on all other particles in the universe. Research scientists have said of the Higgs Boson that "The Higgs boson is interesting because it is the only reasonable explanation we have for the origin of mass". Finally, students will conclude by looking at supersymmetry, extra dimensions and mini-black holes and they will examine whether string theory can be tested at the LHC.

Astrophysics

Astrophysics is the expansive branch of physics that deals with the physicality of the universe. This area of physics looks at stars, planets, and galaxies. We will examine the lifecycle of stars, from a cloud of gas to a red giant or supergiant and then to a white dwarf or black hole, and students will be introduced to the Hertzsprung-Russell diagram, which graphically represents stars based on their temperature. We will discuss the luminosity and temperature of stars and the distance between them. We will also discuss the size and origin of the universe and we will examine how much we really know about the universe. What is the big bang theory? Is it a plausible explanation for the beginning of the universe? How can the universe arise out of nothingness? What existed before space and time? What is dark matter? How much of our universe does it comprise? If we don't know much about dark matter, how much of the universe do we understand?