Why Bother with Relativity (1)

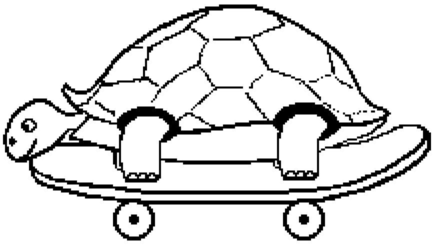
Introduction

Most people have unwittingly built themselves an ‘***intuitive***’ mental model of how the world around them functions (based mainly on ***Newtonian*** mechanics, whether they know it or not!) In our every-day experience, this way if thinking is adequate, but in unfamiliar situations, it can turn out to be flawed. This is especially true where the ***speed of light*** is approached, as is nearly always the case in ***high energy particle physics***.

In order to begin to understand what is going on in the BABAR experiment, it is necessary to get to grips with the basics of ***relativity***. The two apparent paradoxes explored below should be enough to convince you of this!

‘Paradox’ 1 : Stationary …

A tortoise on a skateboard travelling in a straight line at constant velocity carries two negative electric charges on its back. As far as the tortoise is concerned, the charges are stationary, and the repulsive force between them is given by ***Coulomb’s Law***.



… or moving?

However, as far as a sparrow perched on top of a tree, observing the tortoise from a distance is concerned, the charges are moving. The sparrow knows that when two parallel current-carrying wires are placed next to each other, they are attracted to each other by a magnetic force. The charges that the tortoise is carrying are moving like the charges in the parallel wires. Therefore, the sparrow sees not only the Coulomb repulsion, but an ***extra*** magnetic attractive force.

Point to Ponder #1 : Is this nonsense?

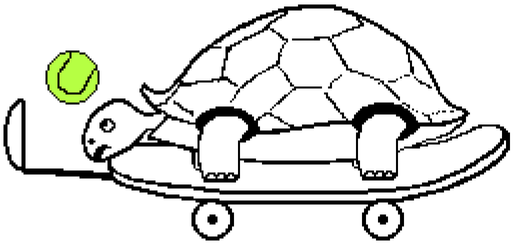
Surely the ***strength*** of the force between the charges is a ***fixed*** quantity that doesn’t depend on ***who*** is looking at them! Or does it?

Why Bother with Relativity (2)

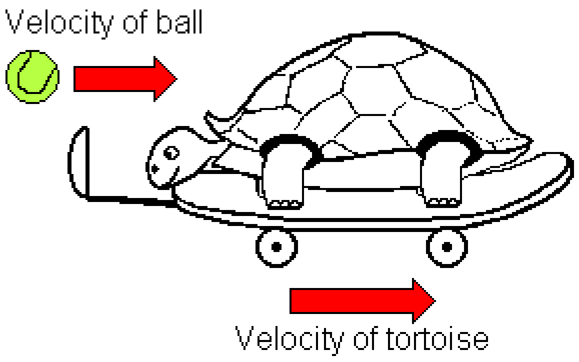
'Paradox' 2 : On reflection ...

Let's assume that the tortoise brings its skateboard to a halt, and attaches a ***mirror*** to the front so that it can vainly contemplate its reptilian splendour. If the tortoise is to see its reflection, ***light*** must travel from the tortoise to the mirror and back again into its eye.

We can picture this idea simply by imagining that there is a machine in front of the tortoise firing ***tennis balls*** at it. These ***deflect*** off of the tortoise onto the mirror and bounce back again, in the same way as the light does. Some of the balls may even hit the tortoise in the eye after hitting the mirror!



Not particularly happy with this unmerited bombardment, the tortoise gets back on its skateboard, and a kind friend gives it a shove backwards, away from the machine. Now, any projectiles the machine fires at the tortoise will take ***longer*** to arrive, as it is moving away from them. If the tortoise is given a big enough push, it will move faster than the balls, which will ***never*** reach the tortoise or the mirror, and certainly won't be able to deflect off the tortoise and the mirror, into the tortoise's eye!



Let's now dim the lighting and replace the machine with a powerful torch, pointed at the tortoise, and 'firing' ***light*** at it. When the tortoise is sitting still, it can see itself in the mirror. If we pushed the tortoise so that it was moving ***faster*** than the speed of light, by our analogy, the light would stop hitting the mirror, and the tortoise would no longer be able to see itself. Its reflection would ***vanish***!

Point to Ponder #2 : Is this correct?

Would its reflection ***really*** disappear? Or do you think the analogy with the tennis ball firing machine break down near the speed of light?

Why Bother with Relativity? (3)

An Explanation : Cue Einstein!

In 1905, Albert Einstein, probably now the world's most famous physicist, published a paper on what he called the '***Special Theory of Relativity'***. This was remarkable, as he was a failure at school, and was a lowly clerk in a Swiss patent office at the time! This ground-breaking paper provided an explanation for the problems outlined on the previous two pages, and transformed the way scientists consider space and time. Einstein published a follow-up paper on ***General Relativity*** in 1915, and collected a ***Nobel Prize*** a couple of years later for some unrelated work on the photoelectric effect.

Special Relativity

The whole of ***Special Relativity*** is based on the following fundamental ideas :

The ***laws of physics*** are **the same** in all inertial frames.

The ***speed of light*** is ***the same*** in all inertial frames.

No material body can travel ***faster*** than the speed of light.

An '***inertial frame'*** is simply a system that is moving at a ***constant velocity*** along a ***straight line*** (i.e. with no rotation or acceleration).

In the first example, the tortoise on a skateboard was in one inertial frame, and the sparrow was in another.

Point to Ponder #3 : Is it 'real'?

Is this just an impractical theoretical description, or can you think of any ***real-life*** examples of inertial frames?

Photo of Albert Einstein. Courtesy of Tracey Keifer. Emilio Segre Visual Archives. American Institute of Physics.

Why Bother with Relativity (4)

Inertial Frames

Someone in an inertial frame ***cannot*** tell whether they are ***moving***, or whether they are ***stationary*** and things around them are moving. You've probably experienced this feeling when you are sitting on a train waiting for it to leave the station, and another train pulls in beside you. Often, this creates the illusion that you have started moving, and that the other train is stationary. This effect is the source of the quote commonly attributed to Einstein (which he probably never said) :

"Excuse me, at what time does ***Manchester*** get to the ***train***?" *

As far as he was concerned, it didn't matter if the train was moving and the earth was stationary, or if the earth was moving and the train was stationary. The ***net result*** would be ***identical***, and someone sitting on the train or outside it wouldn't be able to discern the difference!

At Last ... The Answers!

The solution to the ***first*** 'paradox' about the electric charges is too complicated to explain here, and is to do with the nature of electricity and magnetism in a non-stationary situation. This is a third year degree level topic .....

The solution to the ***second*** 'paradox' is simply that the ***speed of light*** is ***the same*** in all inertial frames. It is impossible for the tortoise to 'escape' from the light beam, no matter how fast it goes, as the speed of light is ***always 299,792,458 ms^{-1}***! Thus, it will always be able to see its reflection in the mirror. This is difficult for us to imagine, but we have to accept it, as it is how the universe fits together!

Key Concept #1

No material body can travel ***faster*** than the ***speed of light***.

---

* *Actually Oxford, but if he didn't actually say it then it may as well have been Manchester!*

Relativity and Time (1)

Introduction

If we say that the speed of light is the same in all inertial frames, this has serious implications for the concepts we hold about ***time*** and ***distance***, as speed is measured in units of $\frac{dist}{time}$.

There are several issues we have to think through as a result of this.

The Relative Nature of Simultaneity

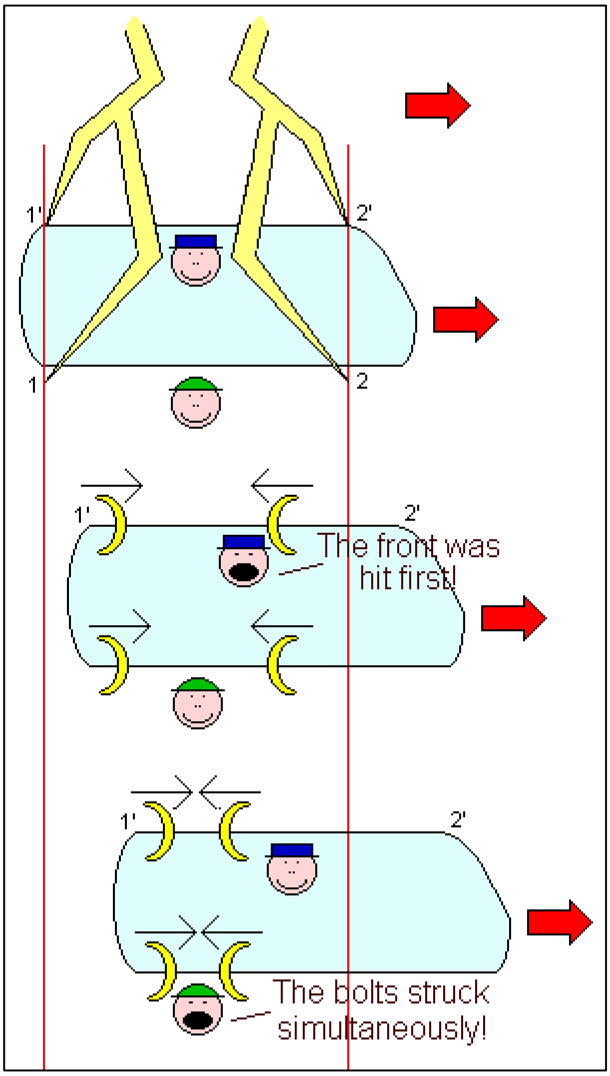
Indeed, it is no longer possible to talk about events happening ***simultaneously***, as can be seen from the following simple story.

Mr. Flat Hat now sits on a train moving near the speed of light, while the Mr. Round Hat remains on the platform. The train and the platform have the misfortune to be struck by lightning at ***both*** ends of the Mr. Flat Hat's compartment.

The crucial question is : ***Which*** lightning bolt struck ***first***?

As far as the ***Mr. Flat Hat*** is concerned, the lightning struck the ***front*** of the train first.

However, the ***Mr. Round Hat*** says that the bolts hit ***simultaneously***.



Point to Ponder #4 : Is this nonsense?

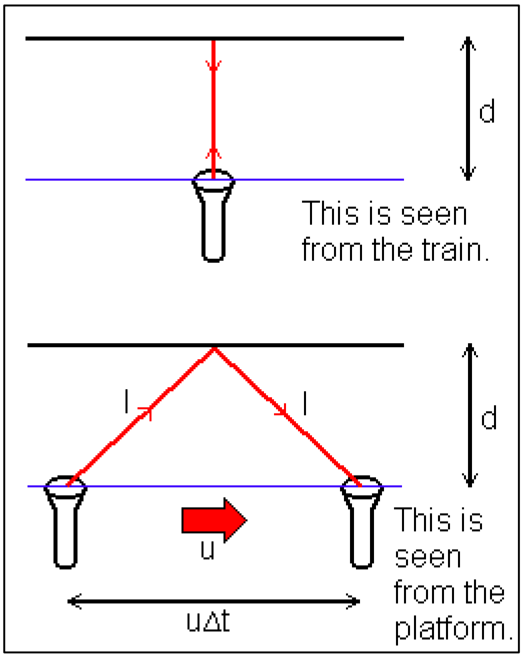
Is it possible to say ***for certain*** whether two events happened ***simultaneously*** or not?

Relativity and Time (2)

Time Dilation

Let's now give Mr. Flat Hat a method of measuring time : a '***light clock'*** consisting of two parallel mirrors with a light beam bouncing between them, perpendicular to the direction of motion. The mirrors are a distance *d* apart, so Mr. Flat Hat sees the round-trip time as $t_0 = \frac{2d}{c}$, where *c* is the speed of light and *d* is the distance between the mirrors.
The light beam bouncing backwards and forwards is like a '***ticker***' similar to the pendulum of a grandfather clock.

The diagram shows the difference between what the Mr. Flat Hat and Mr. Round Hat see. (NB : They observe the same value for *c*, and the same value for *d*.)



This is true for ***all clocks***, not just those based on a bouncing pulse of light. Even a digital clock or a grandfather clock would appear to run more slowly - it is a simple fact that ***moving clocks run slower*** when observed by someone in a ***different inertial frame***.

This phenomenon has actually been ***observed*** using atomic clocks accurate to 0.0001 nanoseconds flown round the world in supersonic aircraft!

Activity #1

Use ***Worksheet 1*** and the hints provided by the program to work out by how much Mr. Round Hat sees the round-trip time ***extended***.

Relativity and Time (3)

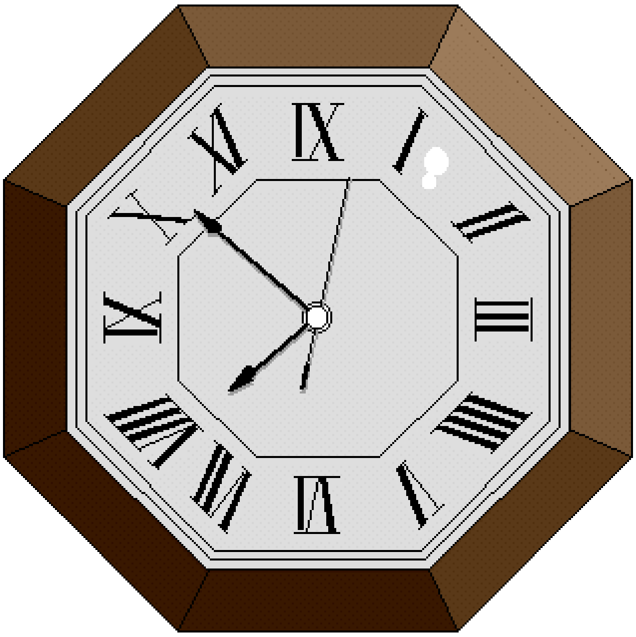
The Time Dilation Factor

The factor by which Mr. Round Hat saw the time extended by (the ***time dilation factor***) is given the symbol g (gamma), and is usually referred to as the ‘***gamma factor’***. g is always greater than 1, and is very close to 1 at low (‘every-day’) velocities, where there is no appreciable time dilation.

In ***Activity 1***, you should have found that

$$g = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

As far as Mr. Round Hat is concerned, the light beam took ***longer*** to make the round-trip, as it has had to travel ***further***. Our everyday experience of time is that it goes by at a constant rate, but this isn’t actually what happens!



If we accept Einstein’s word ***that all observers obtain the same value when they measure the speed of light***, some other ‘constant’ has to give, and in this case it is time.

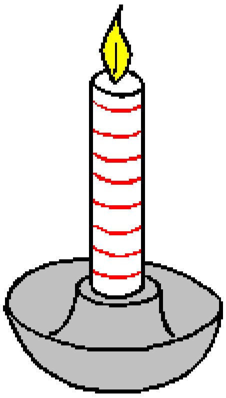
Key Concept #2

Forget the idea that ***clocks*** measure something ***pre-existing*** called ***time***!

Relativity and Energy (1)

Introduction

Candles were often used as clocks in the middle-ages - they ***burn*** at a steady rate and can measure time reasonably accurately.

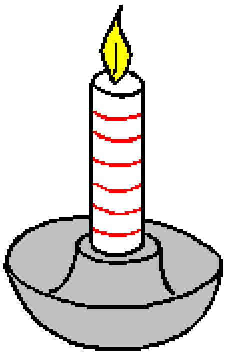


There are a couple of ways we can make a candle ***burn for longer***.

One is by using a candle with ***more wax*** in it, i.e. one that contains ***more fuel energy*** for burning.

The other is by placing the candle on the fast-moving ***train*** and ***observing*** it from the ***platform*** - the candle is as subject to ***time dilation*** as described in the previous section, and lasts for longer.

(NB. Someone on the train would observe the candle as having its normal lifetime.)



Explanation

Why do these candles last longer?

In the ***first*** case it is obvious - the candle contains ***more fuel energy*** and therefore takes longer to burn.

In the ***second*** case, let us assume that the candle must likewise contain more fuel energy, i.e. the total energy of a ***moving*** body is ***greater*** than the total energy of a ***stationary*** body.

Point to Ponder #5 : How much energy?

Have a think about what the fuel energy enhancement factor is likely to be.

Relativity and Energy (2)

It's THAT Equation ...

We can make the fairly educated guess that the fuel energy enhancement factor is g : the ***same*** as the time dilation factor.

Thus,

$$E_{moving} = gE_{rest}$$

The value of E_{rest} is given by what is probably the most famous equation in physics! Of course, it was that man ***Einstein*** who came up with it! It shows that energy and mass are equivalent.

$$\boxed{E_{rest} = mc^2}$$

The rest, as they say, is history!

Thus, when the object is moving with respect to an inertial frame, its energy ***increases*** by a factor of g .
Since ***energy and mass are equivalent***, it makes sense that wherever we see m in a familiar equation, we can replace it with $g\,m$, as g is very close to 1 at the low velocities we are used to.

This means that we can ***increase*** the ***energy*** of a body by ***increasing*** its ***mass*** (a fancy way of saying that more massive candles burn for longer!).

Conversely we can also ***increase*** the ***mass*** of a body by ***increasing*** its ***energy***, e.g. by giving it a ***high velocity*** with respect to another inertial frame

Activity #2

Try to work out what the approximate mass change would be when the internal energy of water is increased, say, by boiling a kettle.* How noticeable is this?

Key Concept #3

Energy and ***mass*** are ***equivalent***. If you increase one, the other automatically increases too.

---

* *The energy required to heat a litre of water is approximately* 3×10^5 *Joules.*

Relativity and Distance

Length Contraction (Lorentz Contraction)

Now, Mr Flat Hat (the one on the train!) holds a rod ***horizontally***, so that it is pointing along the carriage. He decided to measure the l***ength*** of the rod by attaching his mirror to one end, and a torch to the other, then measuring the time it takes for a pulse of light to make the round trip. From the platform, Mr. Round Hat makes the same length measurement ... and gets a ***different*** answer again!

Moving objects appear to be ***shorter*** in the direction of travel when measured from a ***different*** inertial frame.

$$L_{moving} = \frac{L_{rest}}{g}$$

Bear in mind that if the sparrow was also holding a rod, the tortoise would measure it as being shorter, with the same g factor! This is due to the fact that it doesn't matter whether the train is moving or the platform is moving – the net result is the same!

Pictorial Example

$g = 1$ $g = 2$ $g = 3$

This amusing example shows the effect of different g factors very strikingly! Note that only the length in the direction of travel is affected.

Activity #3

Work out what speed the tortoise would have to be going at in order for its g factor to be 2. Express this both in ms^{-1} and as a fraction of c.

Key Concept #4

Moving objects are ***shorter*** than stationary objects. The only ***constant*** for ***all*** inertial frames is the ***speed of light***, and just about everything else must change to accommodate this!

Practical Consequences for Particle Physics (1)

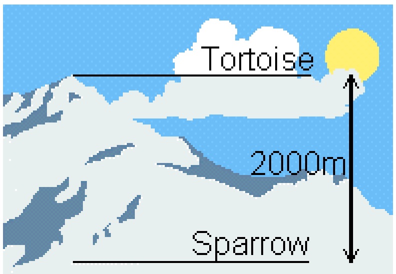
Introduction

Particles can be accelerated very close to the speed of light by electric fields. This means that they are subject to relativistic effects such as ***time dilation*** and ***length contraction***.

Practical Application – Muon Showers

Before the invention of particle accelerators, the only source of particles moving close to the speed of light was ***cosmic ray showers***. These are caused by high energy protons hitting the earth's upper atmosphere, producing a cascade of particles. Most of these decay before reaching the surface of the earth, but muons, which are elementary particles rather like 'heavy electrons' (i.e. they have the same charge as and are more massive than electrons). However, they are unstable, and have a halflife of 1.5 microseconds, i.e. after 1.5 microseconds, half of the original population will have decayed.

Let's put the tortoise at the top of the mountain, the sparrow at the bottom, and give them a muon detector each. The mountain is 2000m high, and the sparrow and tortoise agree that the muons take 6.5 microseconds to get from the top to the bottom. The tortoise measures muons arriving at a rate of 563 per hour.



Activity #2

Use the first part of ***Worksheet*** to work out the rate of muon arrival that the sparrow 'should' measure, ignoring relativistic effects.

The sparrow ***actually*** observes **400** muons per hour, far more than would be expected from non-relativistic calculations! This is another case of ***time dilation***. As far as the muons are concerned, they still have a halflife of 1.5 microseconds, but because they are moving at close to the speed of light, this halflife is ***extended*** in the tortoise and sparrow's inertial frame.

Point to Ponder #6 : Time Out!!

Pause for thought here to make sure you understand the concept that has just been introduced!

Practical Consequences for Particle Physics (2)

Activity #3

Use the second part of **Worksheet 2** and the hints provided by the program to work out the g factor for the muons.

What do the ***muons*** make of all this? Well, as far as they are concerned, they are ***stationary***, and the earth is rapidly coming up to meet them! As far as they are concerned, they retain their halflife of 1.5 microseconds, and the ***distance*** from the top to the bottom of the mountain is ***contracted***!

Activity #4

Use the third part of **Worksheet 2** to work out the height of the mountain in the muons' frame of reference.

Even the most modern state-of-the-art particle accelerators cannot approach the energies of the cosmic ray showers and the velocities of the particles they produce. However, the particles they produce have velocities very close to the speed of light, and any measurements of lifetime or decay length have to be corrected for relativistic effects, as they are velocity-dependent, and would be different if the particles were at rest.

Point to Ponder #7 : What does it mean?

Are the experiences of the tortoise, sparrow and muons ***contradictory*** or ***complementary***? Think about it before moving on!

Key Concept #5

Time dilation and ***length contraction*** go hand in hand!

Why Bother with Particle Physics? (1)

Introduction

Particle physics is a field of study dedicated to investigating the following ***fundamental questions*** about the composition of the universe :

What is the universe made from?

What holds it together?

Over the centuries, our answers to these questions have become more sophisticated. But the more we find out, the more there is still to be discovered ....

Atoms

The idea that the universe is made up of small ‘building blocks’ was first proposed by Democritus, an ancient Greek philosopher who lived from 470 to 380 BC. He called these building blocks ‘atoms’, a name derived from the Greek word ‘atomos’, which means ‘indestructible particle’.

Subatomic Particles

Much later, it became apparent that atoms weren’t as indestructible as had first been thought! In 1897, ***Thomson*** discovered the ***electron***, then in 1909 ***Rutherford*** ‘***split the atom’*** in his famous ***Manchester*** experiment which demonstrated that atoms were not fundamental particles. He also coined much of the terminology used to describe later experiments, such as the term ‘***neutron***’ for the neutral particle discovered by ***Chadwick*** in 1932.

Quarks

With the advent of more and more powerful particle accelerators, ***hundreds*** of other subatomic particles were discovered. It began to look as if there must be another, even more fundamental building block of matter.

The next breakthrough came in 1964, when Gell-Mann and Zweig suggested that particles such as protons and neutrons were made up of other particles called ***quarks***. These acquired their rather unusual name because the original theory predicted that there would be three of them, which fitted in with the phrase “Three quarks for Mr. Mark”, found in “*Finnegan’s Wake*” by James Joyce! (Who says that physicists don’t have a sense of humour?) The quark theory has since been refined, and experimental evidence has shown that there are ***six*** quarks (in order of mass) : up, down, strange, charm, bottom and top. (These last two were originally called ‘truth’ and ‘beauty’, but their names were changed when people decided that this was getting too silly!)

Why Bother with Particle Physics (2)

Fitting it all together ...

Protons are made from two up quarks and a down quark. Neutrons consist of two down quarks and an up quark. We do not see particles made from heavier quarks in everyday situations, as these are ***unstable***, and ***decay*** into lighter, more stable, particles after a short lifetime.

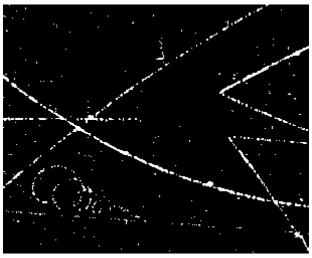
We can only create and observe these unstable particles at very ***high energies***. Since energy and mass are equivalent, it is possible to give two particles extremely large kinetic energies such that when they collide then energy is converted into mass to produce a 'shower' of particles. The technical term for this is an '***event***'.

Key Concept #6

There are ***six*** types of quark, but particles composed of the ***heavier*** ones can only be seen at ***high energies***, are ***unstable***, and have ***short*** decay lifetimes.

Practicalities

In the early days of particle physics, photographic emulsions, then later ***bubble chambers*** and ***spark chambers*** were used to detect particles, which left tracks behind them when they passed through. Since then, techniques have improved considerably, and fully automated ***electronic detectors*** are used in all modern experiments. Some of these can even be programmed to reject all 'uninteresting' events, so the physicists in charge waste less time!



A bubble chamber picture.

The detection chambers are surrounded by a huge ***electromagnet***, which exerts a ***magnetic field*** on the particles. This causes the charged particles to follow ***curved*** paths, making it easier to ***identify*** the particles from their tracks. It also means that the ***momenta*** of the particles can be calculated, as particles with higher momenta bend less in the magnetic field.

Key Concept #7

When two particles collide, some of their ***energy*** may be is converted into ***mass***, producing a shower of ***new*** particles. These can be identified by various means.

The BABAR Project (1)

The B-Factory

In 1999, the 'B-factory' at SLAC (the Stanford Linear Accelerator) opens for business. This will achieve extremely high energies by accelerating electrons and positrons (the electron's positive antiparticle) in opposite directions, then causing them to collide with each other.

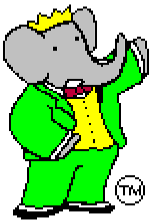
At very high energies, some of these collisions will result in the production of electrically neutral **B** and **anti-B** particles (written as B^0 and $\overline{B^0}$). A B^0 consists of a down quark and an anti-bottom quark, while a $\overline{B^0}$ contains a bottom quark and an anti-down quark.

But why bother?

This experiment is crucial to our ***understanding of the universe***, as it could possibly provide an answer as to why there is so much matter and so little antimatter in the universe.

If, as physicists suspect, ***matter*** and ***antimatter*** were originally created in a ***1:1 ratio***, it would all have annihilated long ago, and we wouldn't be here to speculate about it! It has been suggested that the B^0 and $\overline{B^0}$ particles will have different ***decay rates*** (unlike other particle – antiparticle pairs, which decay symmetrically) which could have led to an initial matter – antimatter ***asymmetry*** in the early universe, and the relative abundance of matter we see today.

But Why BABAR?

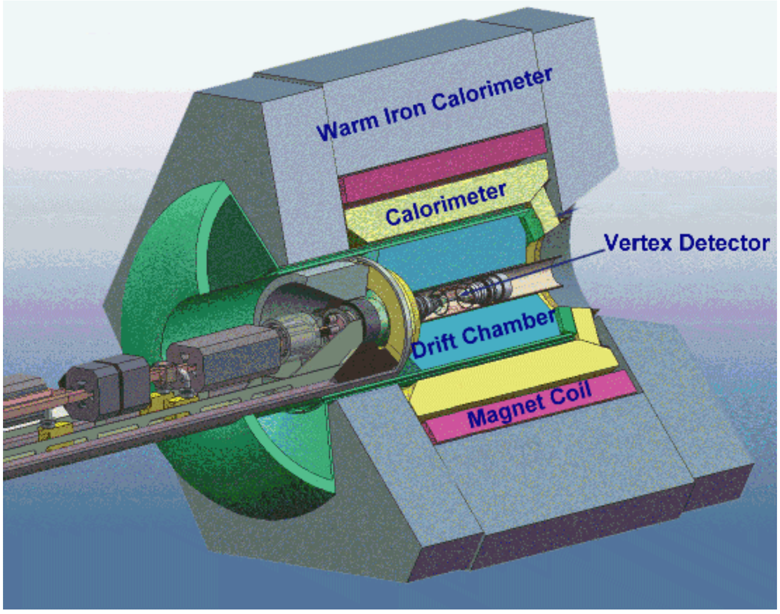


But why is the project called BABAR ? Well, $\overline{B^0}$ is generally pronounced 'B bar', and someone decided that it would be nice to have a cute little elephant as a logo! (At this juncture, it has to be borne in mind that particle physicists will happily talk about 'Penguin decays inducing flavour-changing neutral currents', or 'naked red bottom quarks' without batting an eyelid, so the choice of name is not too surprising! ☺)

The BABAR Project (2)

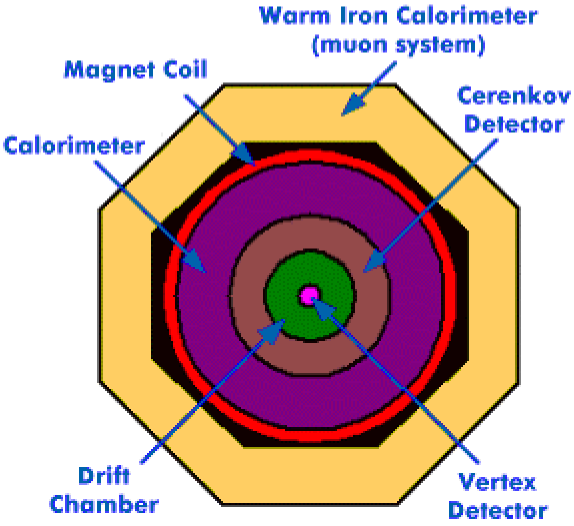
The BABAR Detector

The BABAR detector is able to find the decay points of the B^0 and $\overline{B}^0$ particles, and the ***momenta*** and ***energies*** of the particles produced by the decay of the unstable B^0 and $\overline{B}^0$ particles. From this information, the kinds of particles produced when the B^0 and $\overline{B}^0$ decay can be determined.



The detector has several ‘layers’, each of which is fine-tuned to detect certain types of particles. In this simulation, we will only view the tracks from the innermost parts – the vertex detector and the drift chamber. The magnetic field inside the detector is huge, at 1.5 Tesla (c.f. the earth’s magnetic field at around 0.5 x 10^{-4} Tesla).

The paths of ***charged particles*** are detected in the ***vertex chamber*** and the ***drift chamber***. The ***energies*** and ***momenta*** of photons, electrons and positrons are detected in the calorimeter, and those of most other particles (such as pions, protons and neutrons are detected in the hadron calorimeter. Finally, muons are detected in the warm iron calorimeter. Thus, it is possible to tell the different types of particles apart.



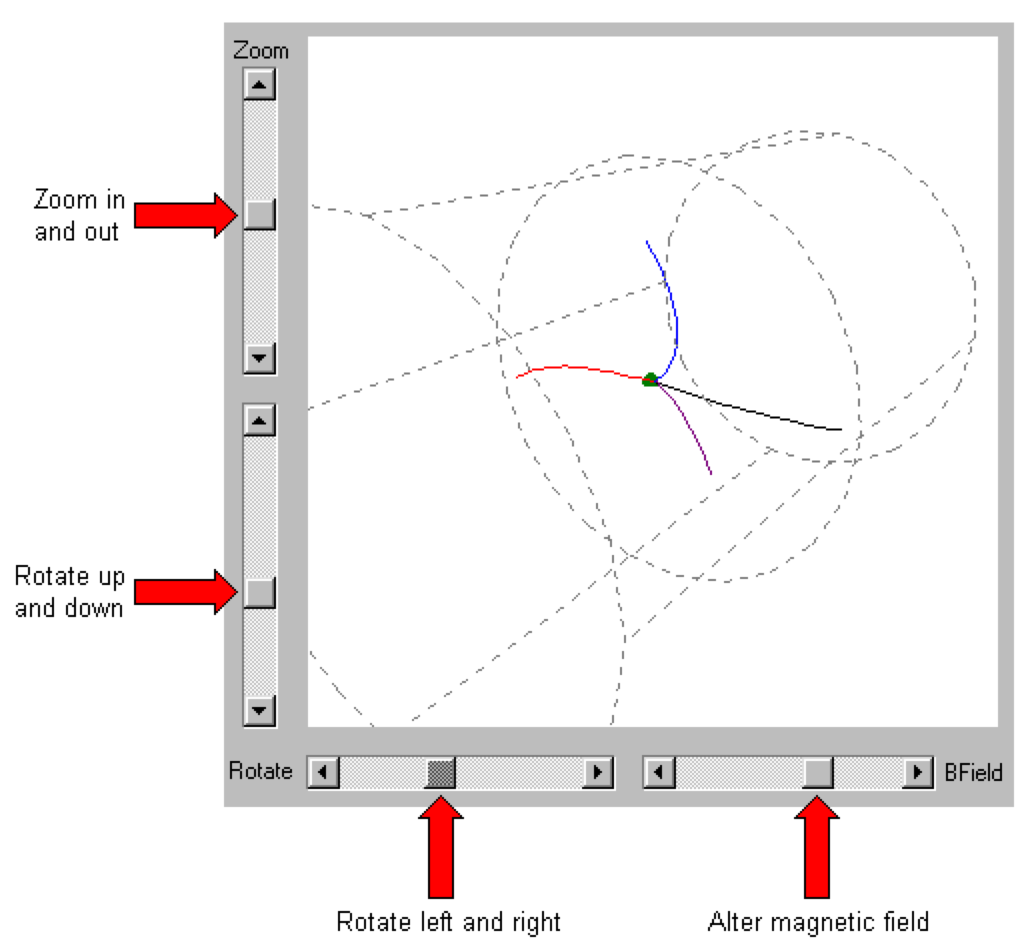
During the event, the particles travel at very close to the ***speed of light,*** meaning that relativistic equations must be used to find their lifetimes before they decay.

Making Measurements (1)

The Viewer Controls

The ***three dimensional*** representation of the inner part of the detector (the vertex and drift chambers) is shown in the right hand panel of the screen. The ***tracks*** represent ***charged particles*** – neutral particles are not detected in this 'layer' of the detector.

Try using the ***slider bars*** to change your view of the event, as shown in the figure below.



- The ***left-top*** slider bar ***zooms in and out***.
- The ***left-bottom*** slider bar ***rotates*** the detector ***up and down***.
- The ***bottom-left*** slider bar ***rotates*** the detector ***left and right***.
- The ***bottom-right*** slider bar adjusts the strength of the ***magnetic field***, which runs ***longitudinally*** along the cylinder.

Making Measurements (2)

The Magnetic Field

The strength of the magnetic field in the actual BABAR detector will be 1.5 Tesla.

Why use a magnetic field? You are probably familiar with the fact that the paths of charged particles in a magnetic field are circular, as quantified by the expression which equates the ***centripetal force*** to the force exerted on the particle by the ***magnetic field*** :

$$\frac{mv^2}{r} = qvB$$

where :

m is the mass of the particle
v is the component of the velocity of the particle perpendicular to the magnetic field.
r is the radius of the circle the particle moves along
q is the charge of the particle
B is the magnetic field

If we cancel a v on each side, and use the fact that the momentum, $p = mv$, we are left with :

$$r = \frac{p}{qB}$$

ie the ***radius*** of the circle is ***small*** and tight for particles with ***small momenta*** in the x-y plane or subject to ***large magnetic fields***.

Note also that the direction of r depends on the sign of q, in other words, ***positively*** and ***negatively*** charged particles will bend in ***opposite directions***.

These facts will help us to ***identify*** the particles produced in the B^0 and $\overline{B^0}$ decays.

Making Measurements (3)

Identifying Particles

Only the decay of a single B^0 particle is shown in the picture – the decay products of the $\overline{B}^0$ are not shown.

Try to ***identify*** the particles produced in the decay sequence from the clues given below. Bear in mind that this part of the detector has no way of sensing the presence of ***neutral*** particles apart from the B^0, which is created at the collision point of the incoming particles

Clues : Particles

- Electrons are negatively charged and very light, which means that they tend to travel rapidly.
- Positrons are like positively charged electrons.
- B^0 particles are neutral and have extremely short lifetimes.
- J/Ψ particles are neutral and have extremely short lifetimes – they decay almost immediately to other particles.
- K^0 particles are neutral and have short lifetimes.
- Negatively-charged pion (p^-) particles are negatively charged and have fairly long lifetimes
- Positively-charged pion (p^+) particles have similar properties to p^-s.

Clues : Decays

In these events, the following decays take place :

- The B^0 decays to a J/Ψ particle and a K^0 particle.
- The J/Ψ decays into an electron and a positron.
- The K^0 decays into a p^+ and a p^-.

Now ***click on the tracks*** to see if you identified them correctly. Click on the ‘Next’ button when you have finished.

Making Measurements (4)

Electronvolts

Boxes containing information about the ***momentum*** of the currently selected particle should have appeared beside the box containing the particle’s name.

The upper box shows the momentum in ***SI units***, ie kgm/s. These are rather unwieldy when talking about particles, so a new unit of measurement is introduced – the ***electronvolt***.

One electronvolt is defined as the ***change in potential energy*** when one electron is moved across a potential difference of 1V, i.e. ***1eV = 1.602e-19 Joules***.

In particle physics, it is convenient to measure ***energies*** in ***eV***, and it is possible then to measure ***masses*** in units of ***eV/c2*** (since $E = mc^2$) and ***momenta*** in units of ***eV/c***.

Try to get used to the concept of an electronvolt before moving on …

Finding the K^0 particle

The K^0 particle decays to a positively and negatively charged pion pair ($p^+ p^-$ pair), so once you have identified these correctly, it is possible to gain more information about the K^0.

Click on the p^+ and the p^- particles, and . Once you have done this, the ‘Next’ button will appear, so click on it to reveal the K^0 and move onto the next section.

The K0’s true lifetime

Now, ***click on the K^0*** to find out some information about it.

As the K^0 is travelling so rapidly (note its velocity!) it is subject to ***relativistic effects*** such ***as time dilation*** (as were the muons coming down the mountain).

In order to calculate the K^0’s ***lifetime in its own inertial frame***, we first need to find its ***gamma factor***, and its ***lifetime in our inertial frame***.

Insert the ***velocity*** of the K^0 in the equation you worked out on worksheet 1 to find its ***gamma factor***.

Now, use the ***velocity*** and the ***length*** of the K^0’s track to find track to find its lifetime in ***our*** inertial frame, then use the ***gamma factor*** to find its ***lifetime in its own inertial frame*** (i.e. its lifetime when it is at rest). When you have done this, click on the ‘Next’ button, and select the answer you think is correct. Once you have answered correctly, you can move onto the final part.

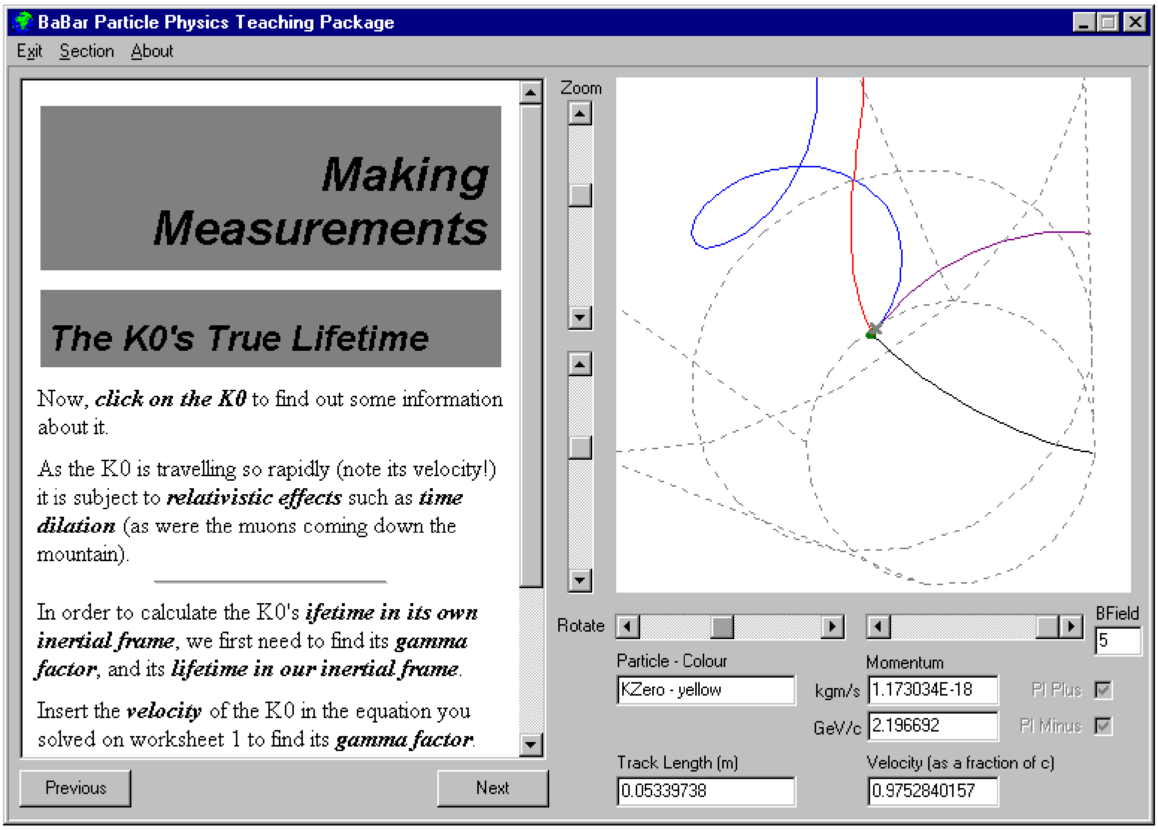
Making Measurements (5)

Many Events

In experimental physics, we need to use ***a lot of data*** to reduce errors, and to make sure that the effects we see are typical, rather than special cases.

Use the ***'Event' control*** that has just appeared at the bottom-right of the screen to have a look at some more examples of the decay we have just been looking at. Click on the 'continue' button to go through the stages of calculating the lifetime of the K^0 for any events that look interesting. Is the lifetime always the same, or does it vary?

If you examined a huge number of events, and plotted a histogram of the K^0 lifetimes, you would be able to work out the particle's ***halflife*** – just as a population of unstable radioactive atoms has a halflife, so does a population of unstable K^0 particles.



Making Measurements

The K0's True Lifetime

Now, ***click on the K0*** to find out some information about it.

As the K0 is travelling so rapidly (note its velocity!) it is subject to ***relativistic effects*** such as ***time dilation*** (as were the muons coming down the mountain).

In order to calculate the K0's ***lifetime in its own inertial frame***, we first need to find its ***gamma factor***, and its ***lifetime in our inertial frame***.

Insert the ***velocity*** of the K0 in the equation you solved on worksheet 1 to find its ***gamma factor***.

BField: 5

Particle - Colour: KZero - yellow

Momentum: kgm/s 1.173034E-18; GeV/c 2.196692

PI Plus ☑

PI Minus ☑

Track Length (m): 0.05339738

Velocity (as a fraction of c): 0.9752840157

That's all folks!!

You have now come to the end! You might like to look back at some of the earlier sections using the 'Section' menu at the top of the screen. Or just play with the particle detector!