A New Leaf in Time

Artwork by Billie Rebecca Walker, and Richard Walker
Text by David Alan Walker

A book about photosynthesis and how green creatures have shaped the world. For readers between nine and one hundred and nine

Artists at work by the tree-house

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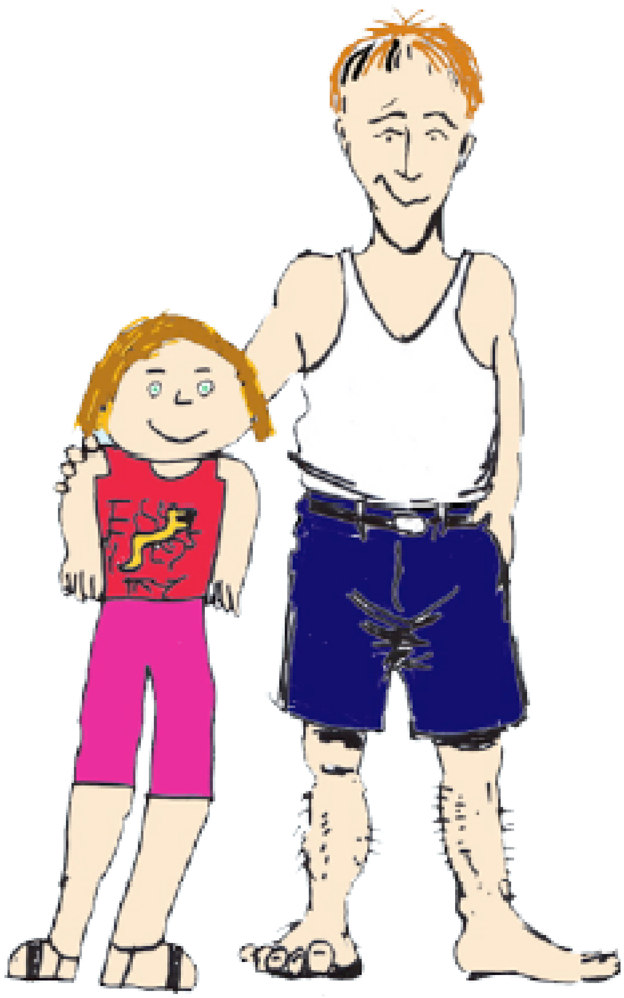
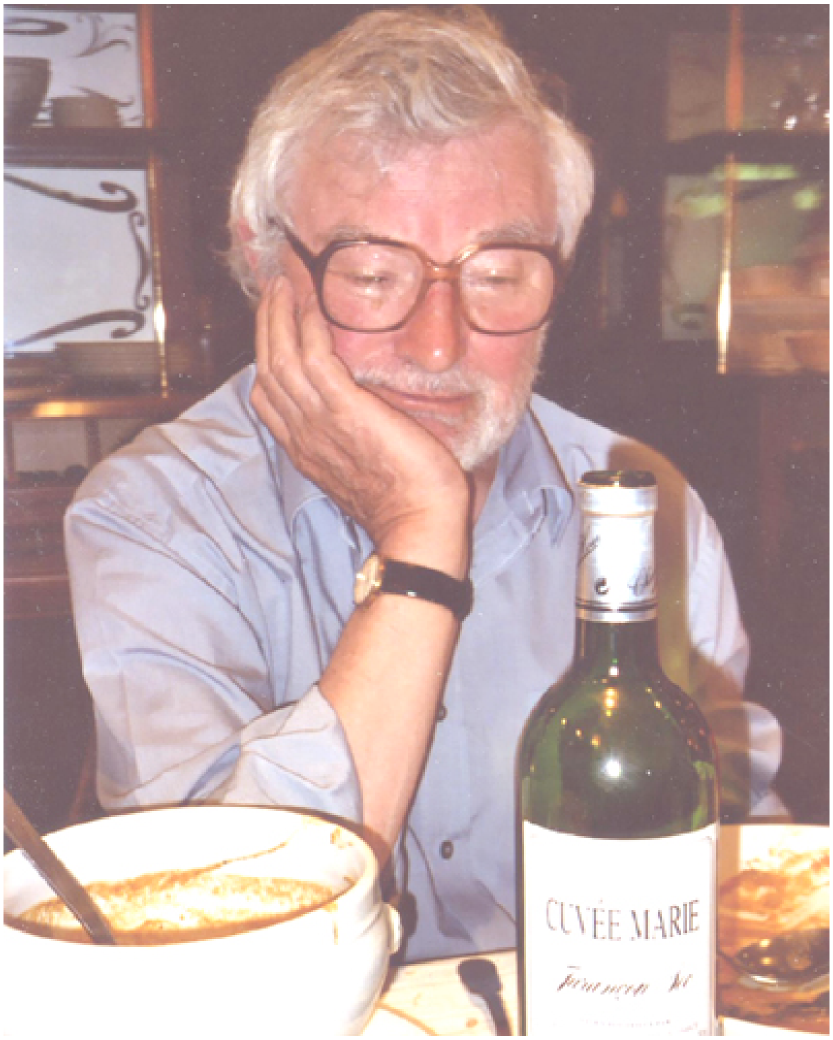


Self Portraits by Billie Rebecca* and her father Richard

*When she is not drawing, Billie also plays a key role in this story

Text by David Alan Walker



When he is not busy writing, he also plays a part in this story as Billie's Grandfather; 'the Prof'

General Introduction. July 2006

Back in 1978, in the days when you could still buy a derelict cottage in a remote part of Northumberland for a song, my father-in-law did just that. His intention was that it might occasionally lure my wife and our two children (his only grandchildren) back to our northern roots. It did. Making it habitable became a labour of love. All us have come to regard it as a place of escape. Like the lighthouse keeper's horse (which wasn't ridden much, of course) we didn't get there very often in the early days but, in retirement, we spend about half our days there. Our kids get there when they can. We have only one grandchild, my son's daughter, Billie.. She will be twelve in December (2006) and, for the moment, enjoys fooling about in the burn just as our two did at the same age and, like me, still do. This book, if it can be called that, was largely intended for her entertainment when the weather was unkind. It has also allowed me two indulgences. Ever since I read some of the books of Fabre as a child I have warmed to scientific writing that is simple, entertaining and irreverent. The advent of the Internet overwhelmed me with the treasures that it can bring at the click of a mouse. So, like Billie on rainy days, I have (with her active involvement) attempted an explanation of one or two (sometimes quite difficult) concepts in the hope that it might be possible to do this at several levels.

At the moment there are 7 chapters in various stages of completion. Where these are heading may be more apparent to you, the reader, than it is to me. I follow my nose. I have always been fascinated by energy transduction and most recently in current thinking about the way in which photosynthetic organisms have shaped our planet. The cyanobacteria beckon in chapter five. Much checking and tidying needs to be done. I have no thoughts about eventual publication but writing is like painting in the sense that it demands to be looked at if it is not to be more than a purely personal indulgence.

What's it all about?

It’s a wildly ambitious attempt to describe a fundamental bit of science in a way that will be both interesting and readily understood by both children and grown-ups.

When (and if) finished, it will be possible to print it on to paper or read it on a computer screen. However, if you are ‘on-line’ (especially since broadband is becoming more accessible, cheaper and faster by the day) and connected to the internet, a mouse click should take you to all manner of interesting places. These ‘hyperlinks’ are marked by dashed boxes. Those outlined in blue are intended to be of most general interest, those in green seriously scientific (though the difference between these two has often been difficult to determine.

Then there are hyperlinks in orange. If you have sound enabled on your computer, these may reward you with a snatch of music. Not, perhaps, the best thing to click on if you happen to be in a library or regard such frivolity as inappropriate.

But what’s it all about? Simply a story about the way in which green creatures changed the world.

Chapter One

Amber becomes electrons

Billie, Shirley and Richard at work
and keeping cool

"What are you doing?" said Emily

"Drawing pictures for my Grand-dad's new book" said Billie

"What's it about?""

"Photosynthesis" said Billie, in the sort of voice that implied that Emily should have guessed that.

"Done that at school" said Emily, in the sort of voice that implied that Billie should have known that. "How leaves are green because they are full of chlorophyll and, when the sun shines, they make glucose out of CO_2"

That's right" said Billie, cautiously. "but Grand-dad (that's 'The Prof') says it's not really glucose and there's a lot more to it than that. The most important bit is how green plants make electricity from sunlight. *That*, he says, is why the world is like it is."

"Hang on" said Emily, just a shade rudely. "Leaves can't make electricity. Does he know what he is talking about?"

"He ought to. He's a Professor of Photosynthesis!" This was said with a touch of triumph ; a sense of "beat that". But Billie wasn't a girl to exaggerate so she added "at least he used to be but, now he's retired, he says he's past his sell by date".

Then Billie had an idea. "You could come and meet him if you like. He lives with Curly Shirley (that's Grandma) in Northumberland. They have a cottage and a stream and they got Bill the Builder to build a tree-house for me there. Grand-dad made some bits though." she added kindly.

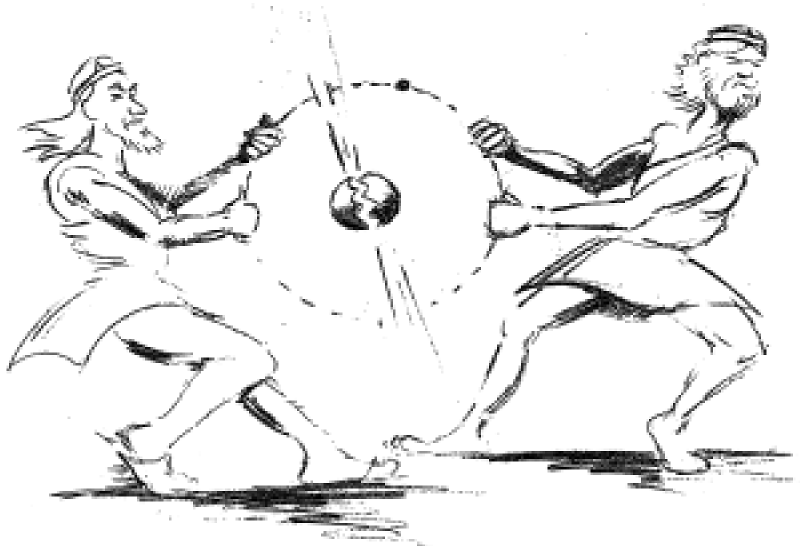
So that it is how Billie and Emily and 'The Prof' came to be sitting in a tree-house by a burn (that's what you call a stream in Northumberland) deep in learned conversation about photosynthesis.

"Just as well you told Emily that I was past my sell by date" said 'The Prof' "and not a man of infinite re-source and sagacity". (Grand-dad was inordinately fond of quotations and literary allusions and a great admirer of Rudyard Kipling).

"Where to start? asked 'The Prof' Do you know how a bikini got its name"?

The two girls exchanged glances. but 'The Prof' ignored this and continued.

"Back in 1808, when Napoleon was in his prime, an English chemist called John Dalton said that everything must be made of tiny particles of matter called atoms. Of course the Greeks----



----had a word for it because it had been on their minds a couple of thousand years earlier".

('The Prof' was starting to wander a little here but he had a very polite audience and they didn't interrupt)

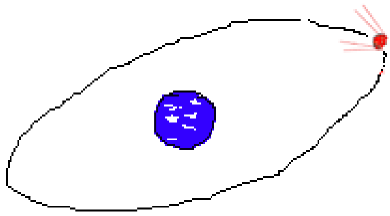
"So that's why Dalton followed the ancient Greeks and called his particles atoms. For a long time after that it didn't seem possible to have anything smaller than atoms. So, in 1946, just after an atomic bomb was tested on a Pacific island called the Bikini Atoll, a French designer called his new swimsuit a bikini.

It didn't seem possible, *then,* that young women could possibly wear anything smaller. So the name was very appropriate and it stuck."

The two girls exchanged more glances

Here 'The Prof' asked Billie to draw a picture of the world with a satellite circling around it.

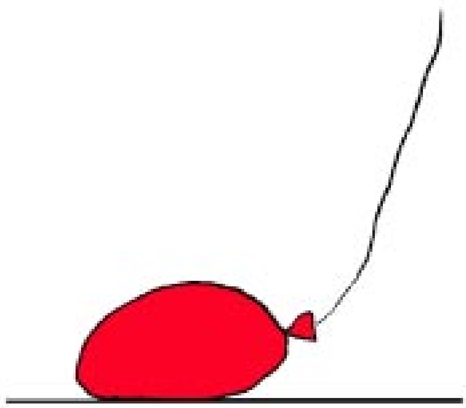
This ⇒



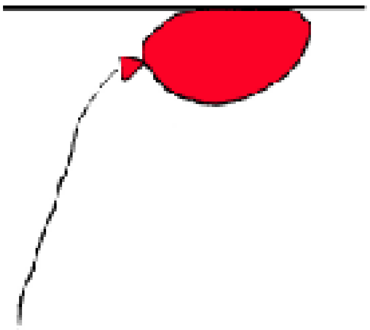
is what Billie drew

"If you had asked me to draw an atom I would have drawn it in much the same way." said 'The Prof' "There are lots of different atoms and a hydrogen atom is the smallest and simplest of them all. Actually it's not really too like a satellite going round the world but it will do. The big bit in the middle is called a proton and *its* satellite is called an electron".

This is how Billie's Dad, Richard,drew a hydrogen atom for one of The Prof's books..The man is the proton ,It says H^+ on his shirt, ('cos H^+ stands for proton).and e^- stands for electron



'The Prof' reached for a toy balloon that was lying on the floor. He held it up to the ceiling of the tree house and then let it go. It drifted back down to the floor.



Then he rubbed the balloon against the woollen sweater that he was wearing and held it up again. This time it stuck.

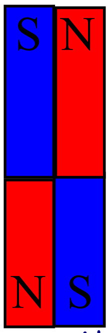
"The Greeks did this sort of thing, way back", The Prof' said "by rubbing amber with fur. That's how the Greek word for 'amber' became the English for electron"

"What we think now" he continued "is that when one thing sticks to another, after being rubbed like our balloon, it's because it has an electric charge. There are positive (+) charges and negative (-) charges. Positive charges, hate each other. So do negative charges. Opposite charges, one plus and one minus, love each other. So a hydrogen atom is very content because protons are positive (+) and electrons are negative (-) and hydrogen has one of each.

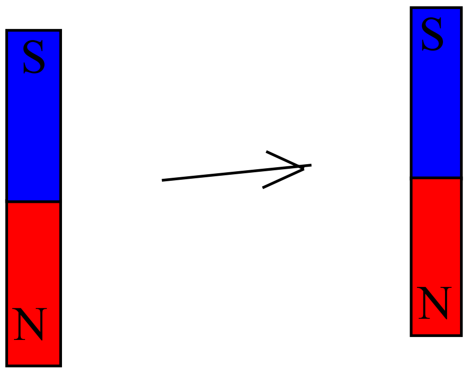
Magnets are much the same."

"Each magnet has a North Pole and a South Pole. North Poles adore South Poles so they attract them. They hate other North Poles and push them away."

'The Prof' not only had a liking for quotations and Rudyard Kipling, and Shakespeare, and stuff like that, he also had a weakness for practical demonstrations. So now he took two bar magnets out of his pocket. They were clinging together like crazy.



Then he turned one of the magnets round and it sprang away from the other one.

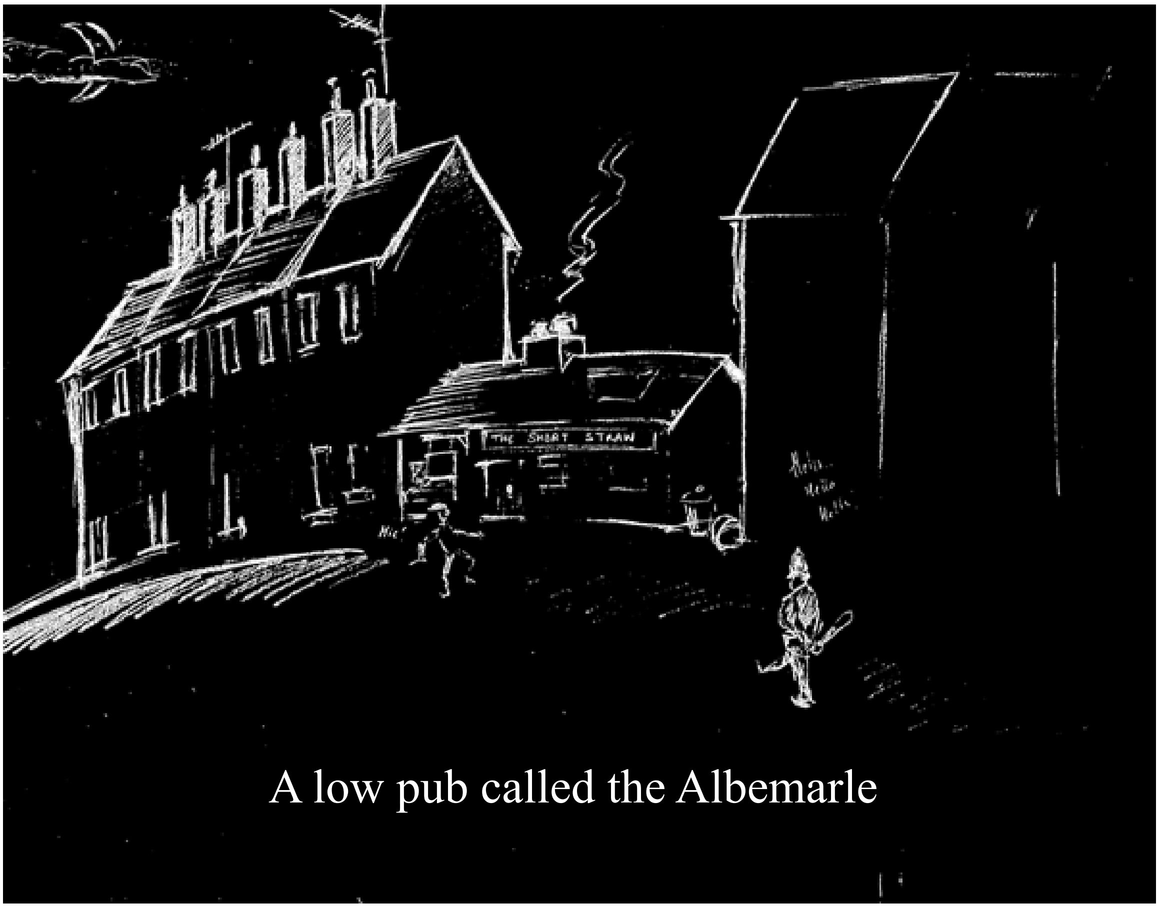


"What's more, electrons spin like tops so they behave like magnets as well.. You can even get magnets to push electrons."

" Name of Faraday mean anything to you? Hailed from the Elephant and Castle in London, worked in Albemarle Street?" continued 'The Prof' as though he expected shaking of heads.

Michael Faraday

[It should be recorded here that Grand-dad (he wasn't 'The Prof' then) had enjoyed many a Saturday night in a low pub, called the 'Queens Head.' in Albemarle Street in South Shields. Indeed this pub was always better known as 'The Albemarle'. This, of course, has absolutely nothing to do with the Albemarle Street in London, where Faraday worked in The Royal Institution, but Grand-dad's mind wanders, as old men's minds do. Besides, the first time that he saw Curly Shirley, back in 1952, it was just a couple of miles from there.]



A low pub called the Albemarle

'Went to the Faraday museum with my Dad " said Billie, trying hard no not to look too pleased with herself but not succeeding. "Discovered how to make electricity, didn't he?"

" Very ,very good" said 'The Prof'

" Wow!" said Emily, looking at Billie with new respect.

"In September 1831 " said 'The Prof ' "Faraday tried, for the fifth time time, to use a magnet to make electricity. This led him to turn a disc of copper between the poles of a magnet. Can you imagine how pleased he must have been when he got an electric current? We do much the same now . We burn coal, oil or whatever, to make steam, use the steam to drive a turbine, use the turbine to turn a wire coil in a magnetic field and Bob's your uncle."

[Actually, 'The Prof ' does have an uncle Bob, but that's neither here nor there].

"By now now, we know that each time the revolving wire gets to the right place the magnet drives electrons down it. That's what an electric current is; a stream of electrons flowing down a wire.

What's more, electrons flow down hill, like the water in our burn"

[All this time, the noise that the burn made, as it rushed by, almost beneath their feet, seemed to echo his words. There had been a lot of rain the day before. The burn was in spate, roaring down the hill, moving big boulders as it went]

"Electrons don't flow down a hill made of earth and stones, of course, but a much more important chemical hill. When we get electrons to flow down hill they can be made to do work for us. With a little help from their friends,green leaves do that too. They kick electrons up hill and make them do work as they run down."

[Here 'The Prof' glanced apologetically at Emily so as not to cause offence]

"That" he said. (as though he was a bit tired of hearing about chlorophyll making glucose but deciding it best to get into that nonsense later) "That's what photosynthesis is really about. That's what changed the world"

At this moment a little gadget on the wall of the tree-house made a buzzing noise. Billie pressed a button. Over a loud-speaker, Curly Shirly's voice said "Time for tea!"

"Thank you, Gran" said Billie and off they all went across the drawbridge, over the burn, and into the cottage.

"Stands the clock at ten to three?"asked Granddad as they arrived.

[He and Curly Shirley had lived in Granchester for a while when they were first married so she knew what he was on about. Billie and Emily were intent on tea so they let this pass.].

After tea, 'The Prof' showed them how, if he rubbed a balloon on his jumper, it would bend a stream of water from the tap. There was much more chat about positive and negative charges.

The next day they were into photons.

Chapter Two

Making water run up hill

"Photosynthesis", said 'The Prof', "goes on in chloroplasts. There are many more chloroplasts in your average leaf than there are people in London"

"They must be very small", said Emily, doubtfully.

"Very, very small" continued 'The Prof',, "and they contain all the green stuff." He pointed out of the tree-house window towards the cottage. "See that thing on the wall. You know what that is, don't you?"

Both the girls nodded. This was a way of saying that, of course, they knew but were too polite to say it out loud.

This is what 'The Prof' was pointing to. It's is a bit of a cheat because it was summer in the story but it will do.

You can see four antennae if you look closely. The dish that catches TV signals fom a satellite is just visible at the right. Two of those sticking up from the roof belong to the people next door. The third one

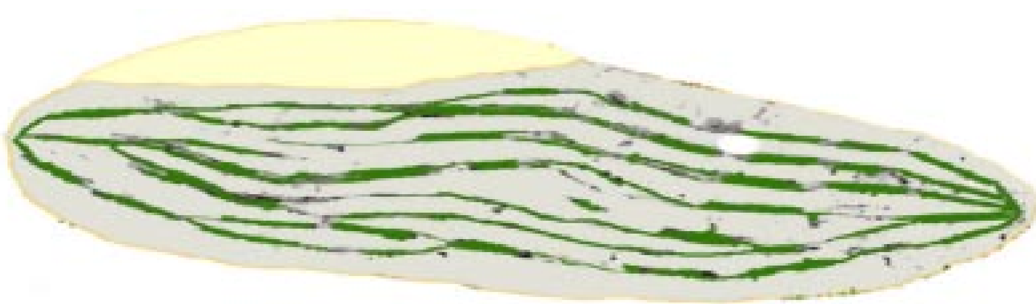
probably doesn't do anything by now but Grand-dad says he is too old to go up there and take it down.

Grand-dad says he wishes he had a big panel of photovoltaic cells on the roof 'cos these would catch light and convert it into electricity just like chloroplasts.Of course they would't work if they were covered in snow. Leaves have the same problem, he says..

"That's the antenna which picks up our television signals from a satellite. At least, it does when it's not covered in snow. The green stuff in leaves is called chlorophyll and it does the same sort of job. It's mixed with proteins and fats and stuff to make antennae which catch the light"

"When do we get to photons?" said Billie

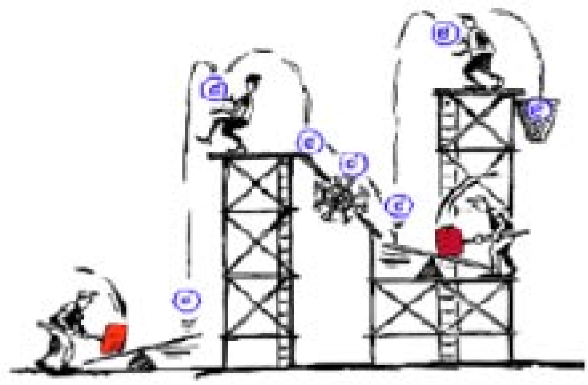
"Right now" said 'The Prof', "The light comes in little packets called photons and, if it is the right colour of light, it gets caught by the chlorophyll antenna.



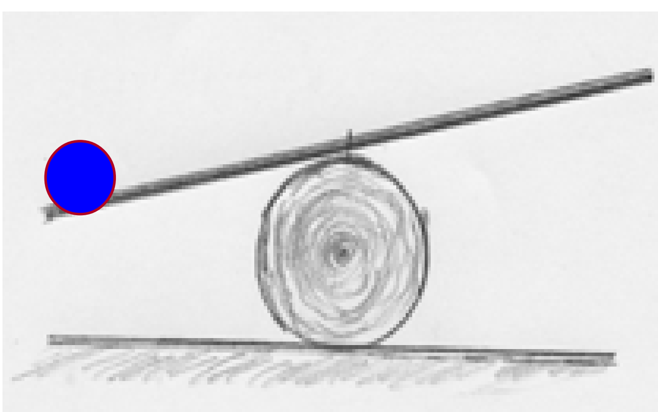
[This is a picture of a chloroplast and the green bits are the chlorophyll antennae which catch the photons. They like catching red photons best.]

'Every photon that's captured kicks an electron up hill. Your Dad (by this 'The Prof', meant Billie's Dad, Richard) once did a cartoon about this which became famous".

"We can put it in here" he added " but, since it's your book, I think we might also do a new one. Who's for making a see-saw?"



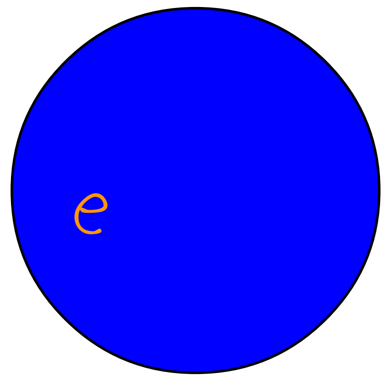
Billie and Emily were a bit surprised by this and thought that they were a bit old to be fooling with see-saws but best to humour Grand-dad.



So this was how a see-saw took shape underneath the tree-house.

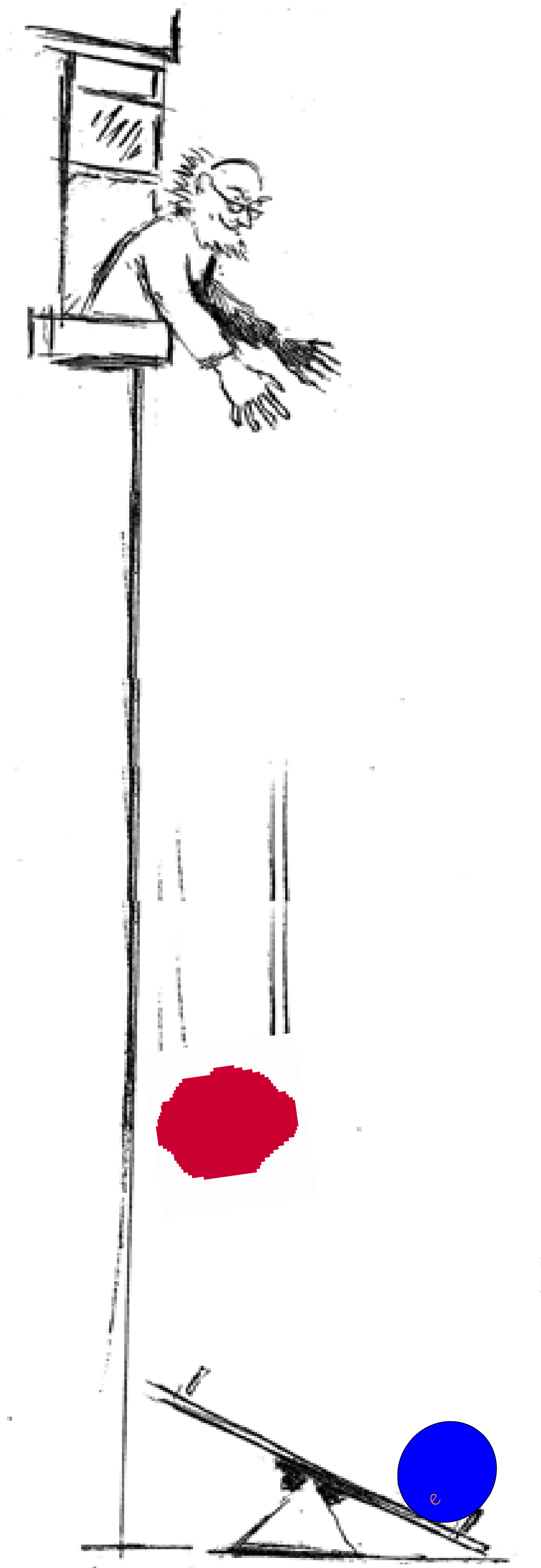
When it was done, 'The Prof' put a ball on one end of the seesaw. It was blue ball and it had an e written on it in orange.

Billie nudged Emily and said.
"Do you think that could be a pretend electron?"

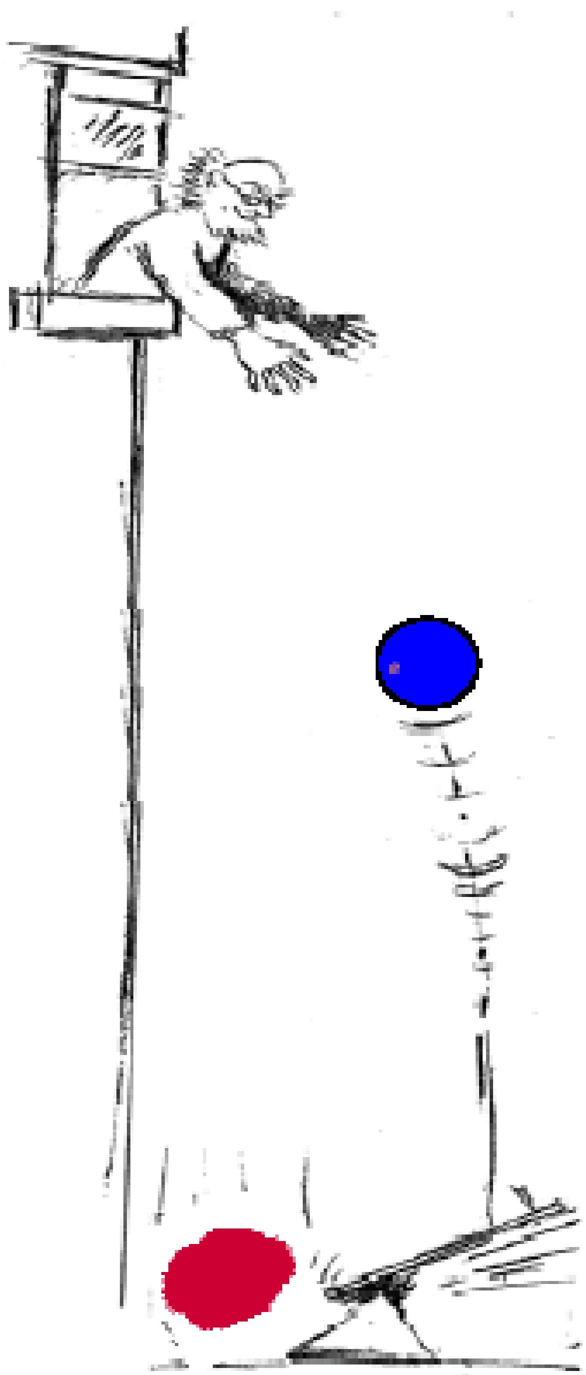


"Waiting to be kicked up hill?" replied Emily.

At this moment, 'The Prof' appeared at the window of the tree-house holding a big red stone in his hand.



"Stand back!" he yelled and dropped the stone carefully on to the other end of the seesaw. The ball leapt so far into the air that,



as he leaned out of the window, 'The Prof' was able to catch it before it fell to the ground.

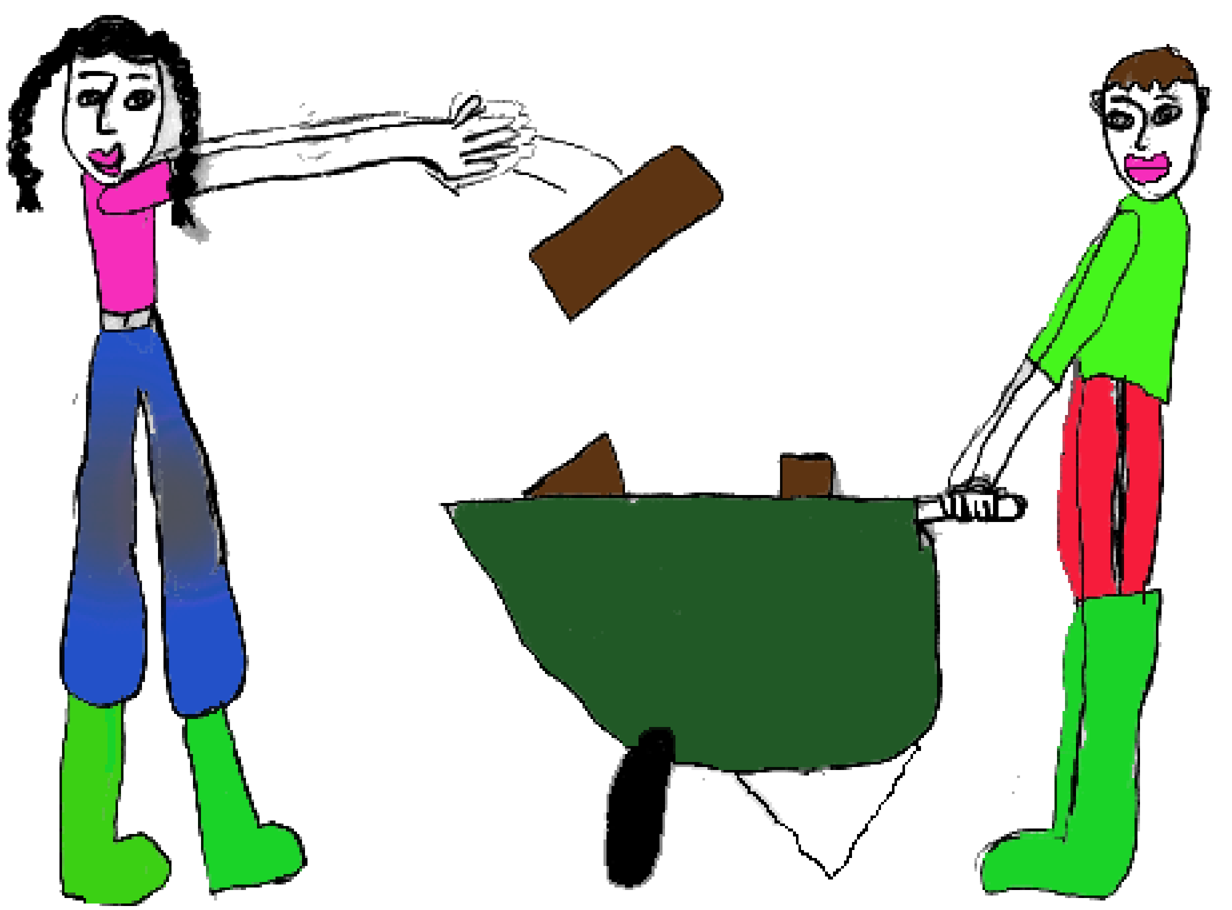
"Eureka" he yelled - "How's that for electron transport?"

"So, as you have seen" he continued "every time a real red photon, rather than a red stone, pretending to be a photon, falls on to the antenna in a chloroplast, an electron is kicked up hill".

"What's more, those electrons moving around inside the antennae in chloroplasts —that's real electricity just like electrons moving along a copper wire on their way to work a light or a computer or whatever.

Chloroplasts use their electron transport, their electricity, to split water into oxygen and hydrogen. Tomorrow, if I can find some bits of platinum wire, I'll show you how we can imitate that.

Hydrogen made from water might soon be a very important fuel" he added thoughtfully.



The girls were quite prepared to believe that but no harm in getting a few logs in —just to be on the safe side

Grand-dad had been making a water-wheel. It bore a passing resemblance to the famous 450 feet high 'London Eye' so, despite being a little under 3 feet from top to bottom, it had inevitably become known as the 'Biddlestone Eye'. A minature mill-race sent water to it from the burn and, as it spun merrily, a dynamo at its hub caused a tiny light to blink like a demented fire-fly.

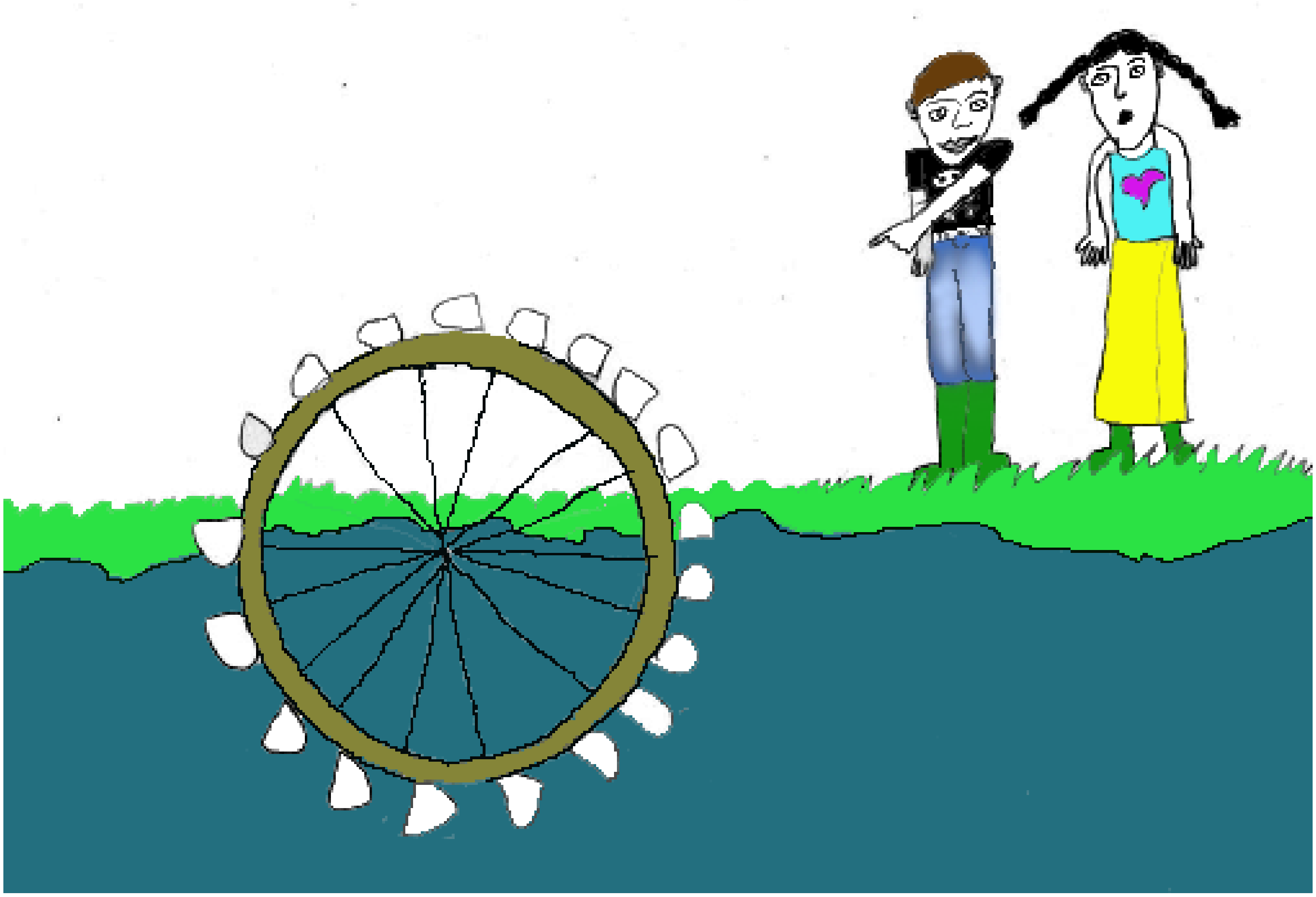
"There we are" grinned 'The Prof' "conversion of sunlight into electrical energy and electricity back to light."

Billie and Emily pondered this. The last bit was clear enough but how did sunlight come into it?

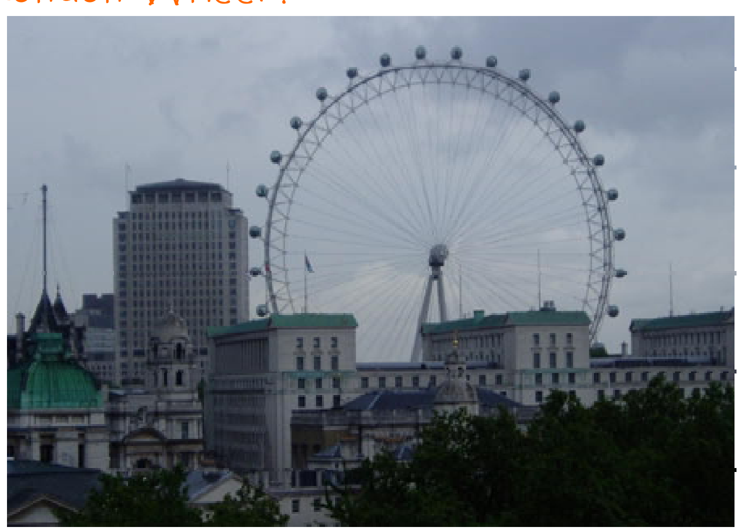
"Think about it" said 'The Prof' "the water in the burn runs down hill but how did it get to the top of the hill in the first place?

The girls went to a little huddle about this and then Billie said "When the sun shines on the sea, water comes off as steam and makes clouds."

"The clouds float over the hills and, when it rains, the water runs down the burn" added Emily triumphantly.

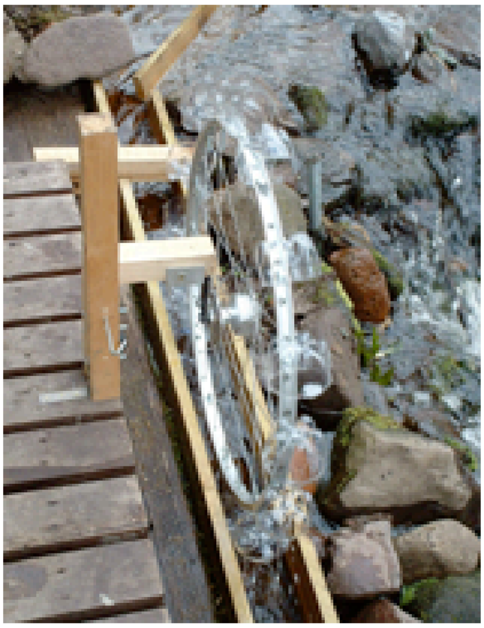


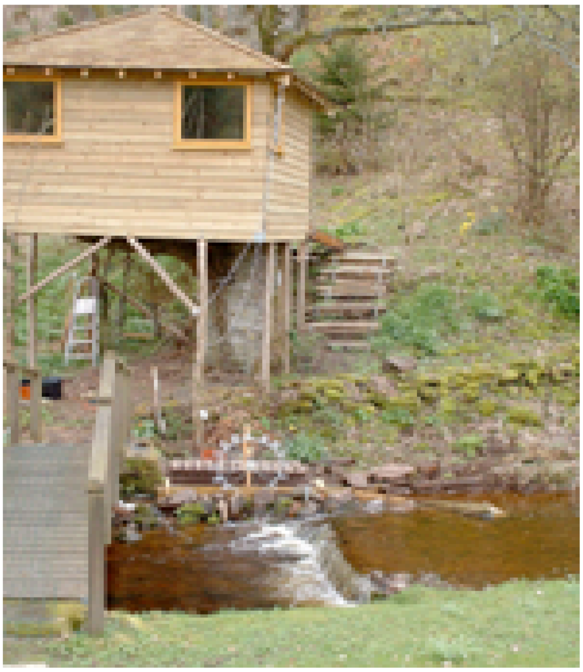
Our artists have used a bit of artistic licence here because it only just dipped into the water. Even so it bore a passing resemblance to the famous 450 feet high 'London Wheel'.



The'London Wheel'.from The Thames and Carlton House Terrace

The Biddlestone Eye





"Well done!" said 'The Prof' "Now, would you believe that leaves contain tiny water wheels that are driven by sunlight?"

This, thought Billie and Emily, was altogether too much to believe but why had 'The Prof' built a water wheel unless he wanted it in this story?

"Lets start with chloroplasts. Each one, as you remember, contains chlorophyll. This is mixed with proteins and fats and other bits and pieces to make the antennae that catch the light. That's where *chloroplasts* make *their* electricity and use it to split water into hydrogen and oxygen. The oxygen escapes into the air and the hydrogen gets added to carbon dioxide to make the plant's food.

But now we get to the really surprising part.. Right inside the chloroplast, close to the antennae, there are these very, very, very tiny wheels. They aren't really turned by water but by pieces of water molecules called *protons*.

"Sounds like nanotechnology" said Billie, daringly

Let's look at this picture again. The big athlete is the proton and it says H^+ on his shirt because that is short for hydrogen ion and that is another name for a proton.

Water is H_2O and it's made up of two bits, H^+ and OH^-, that cling together

[There had been much in the news about 'nanotechnology' and how Prince Charles was almost as worried by it as he was about GM]

"Just so" said 'The Prof', somewhat taken aback "biological nanotechnology you might say. I haven't heard them called *nanoturbines* before but why don't we be the first to do that.?"

There had been much talk of nanoturbines

"This is what happens inside a chloroplast.The electrons that get kicked up hill by sunlight start off as part of water. Take away an electron from hydrogen in a molecule of water and the bit that's left is called a proton. These build up inside a chloroplast membrane like water behind a dam. Then, just like water gushing out of a dam through a turbine to make electricity, the protons gush past the nanoturbines and make them spin round, just like the 'Biddlestone Eye'.

But, instead of making electricity, they make some very special stuff called ATP. This is a way of storing energy, like putting money in a bank. ATP is a bit like a biological banknote. If you and I have plenty of banknotes we can buy food, or wine, or pay Bill the builder to make a tree-house."

"Or go for a holiday in Italy" muttered Curly Shirley, wistfully, as she listened in the background.

The Prof' pretended not to hear. "Plants spend their ATP banknotes on making the things that *they* need like proteins and sugars and fats."

"Now then" he continued, with a 'hoping to be pleased expression' on his face "where did the energy come from to make protons and oxygen out of water?"

"Sunlight" cried Emily

"Photons" cried Billie,

"You're both right, of course" smiled 'The Prof' "*Pho* tons make *pro* tons in photosynthesis"

[This reminded Grand-dad of a copy-editor fom his youth who didn't know her *protons* from her *photons* and, thinking they were spelling errors ,made them all the same]

Chapter Three

"Sugar, ahh,
Honey, honey.
You are my candy girl"

"What's wrong with chlorophyll making glucose while the sun shines?" said Emily.

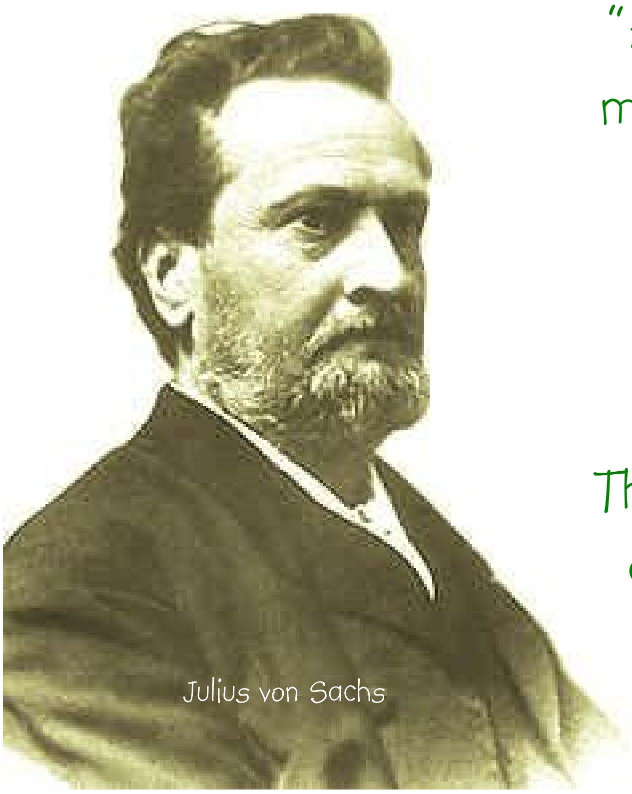
"Like making hay....?" enquired The Prof, kindly.

Emily nodded, doubtfully

"....well some leaves do make stuff that becomes hay and some make sugar. Some plants make oil to go into castor oil beans " finished The Prof (who had worked on castor beans in his youth), "but there's a lot ----

"more to it than that" cried the girls in unison

The Prof ignored this chorus and continued


Julius von Sachs

"Back in 1862 a famous German botanist, called Julius von Sachs, showed that leaves made starch inside (what he called) 'chlorophyll corpuscles'. The starch disappeared in the dark and came back in the light..

Starch is made up of glucose molecules, like beads on a string. Naturally, in Sachs' day, everyone thought that's that.. Bring together light, chlorophyll and CO_2 and you get glucose. Join the glucose molecules end to end and you get starch. [What's more you can stain the starch with iodine and make pictures]"

"Well that's alright then isn't it?" said Emily with an air of told you so.

"Fraid not" said The Prof sadly "These days we know that all of this happens inside the 'chlorophyll-corpuscles'. You know what they are called now don't you?

Yes, chloroplasts. Chlorophylls themselves, the green stuff, are part of the antennae inside chloroplasts. They catch light the light that makes the electricity that drives the rest.

What's more, chloroplasts don't make glucose they make triose phosphates".

At this point Billie and Emily looked at one another as though to say they weren't sure that they wanted to know about triose phosphates but The Prof had the bit between his teeth and wasn't to be reigned in.

"Just like tricycles have three wheels, trioses have three carbon atoms. Just like tricycles need pedals and saddles to work properly, triosephosphates have a few more bits and bobs called phosphate which allow them to do what they have to do.

Triosephosphates can be stored, by being made into starch, and they can go out of the chloroplast and be made into sucrose`

"The ordinary sugar from the super-market 's called sucrose isn't it?" said Billie, innocently.

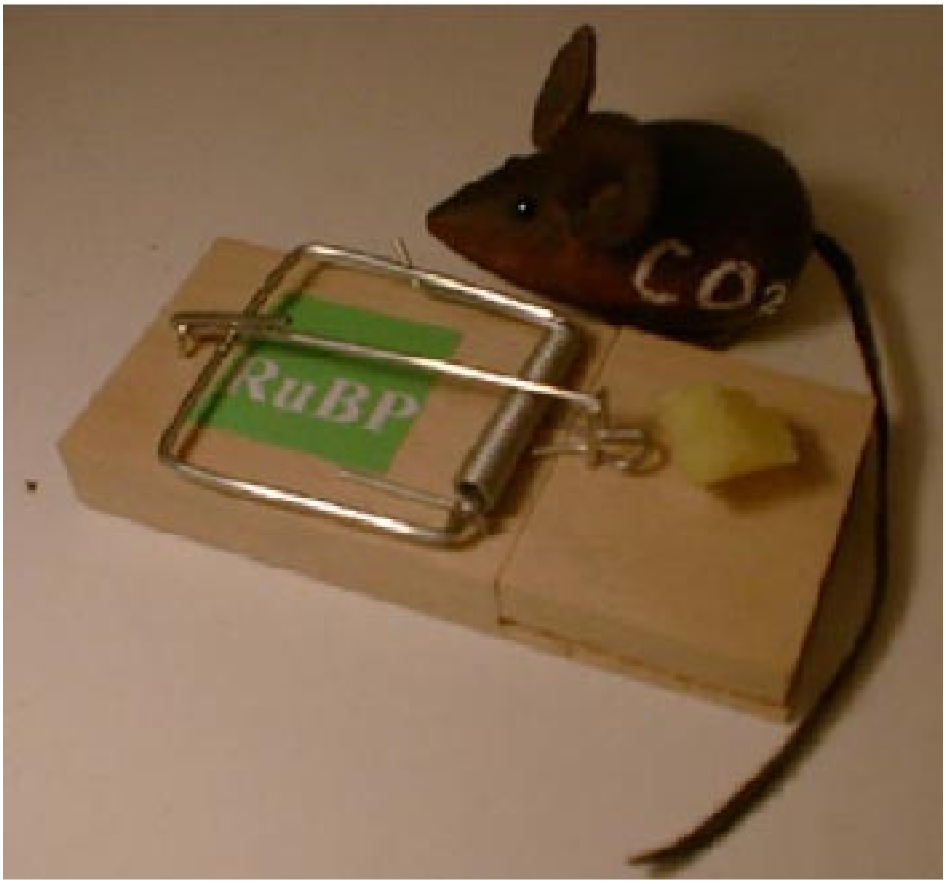
The Prof smiled the sort of smile that meant that he was pleased that Billie knew what sucrose was and continued "Yes and sugar is food for plants too. What's more plants use some of it to make traps that catch CO_2 inside the chloroplasts so that they can go on making it..

'Like mousetraps?' said Billie, sceptically

"Chemical traps. But , like mousetraps, once they catch something they don't let go and they can only be used once."

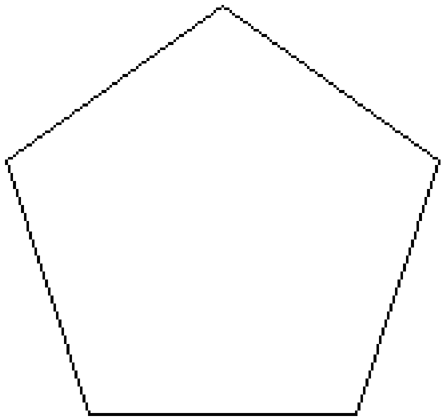
"So, new ones have to be made all of the time. Not only to repace the old ones but so that leaves can catch more and more CO2 and plants can grow".

"When you were both very little I wrote a book called 'Like Clockwork' The Prof continued in a melancholy way as though he was regretting how quickly the years had passed. I put a pretend picture of a CO2 trap in it.. I'll borrow it and put it in here."



"It wasn't a real mouse" he added quickly

"The real traps are pentose phosphates. There's a famous place in the United States called the Pentagon because it's shaped like this.



How many carbon atoms do you suppose a pentose phosphate has if a triose phosphate has three?"

The girls thought about this for a moment and then yelled "Five!"

The Prof nodded as though he expected nothing less than this answer.

"In the picture, said Emily, the mousetrap has RuBP wrtten on it. What does that mean?"

"I'm glad you asked that." said The Prof "Its short for 'ribulose bisphosphate' and, if you were a chemist, you would know that means a pentose with one phosphate at each end"

"Now, if a chemical mousetrap, containing five carbon atoms, catches a pretend mouse containing one, how many carbons do we have?"

"Six sighed the girls" as though being asked to do 5 + 1 = 6 was a bit beneath them.

"And, if the six split straight away into two threes, each containing one phosphate, can you guess what they might be called.?".

'Triose phosphates?' asked Billie.

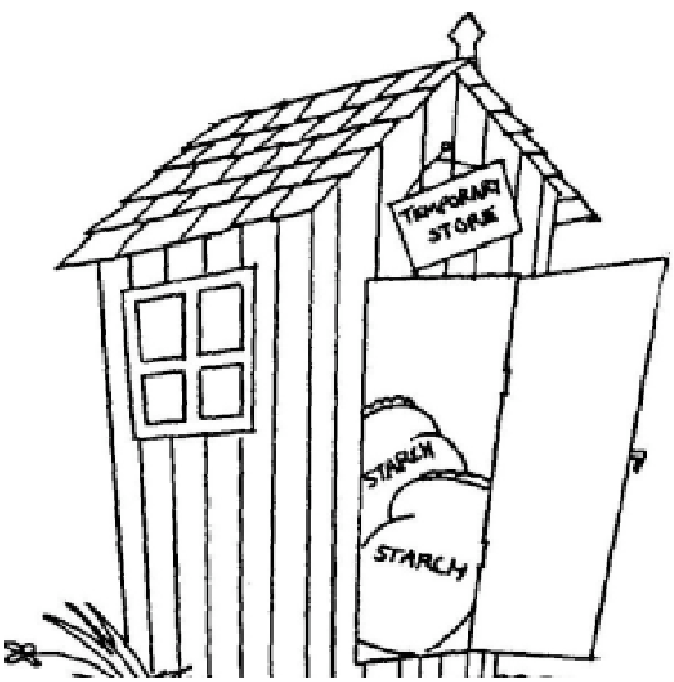
"*Well done!*" cried the Prof who was understandably pround of his ten year old grand-daughter.

"Now the chloroplast has just caught one CO_2 and finished up with two triose phosphates. But it needs to make new traps each containing five carbons. So, as soon as it has caught 3 CO_2s, and therefore has 6 triose phosphates to play with, it shuffles five of them to make three new traps"

"What happens to the one left over?" asked Emily,

" That what it's all about. That's how plants get to grow. As soon as there are triose phosphates to spare, they go from the chloroplasts to be made into sucrose. Then, together with stuff like nitrogen, that roots get from the soil, this sucrose is made into everything that the plant needs. If there are even more triose phosphates to spare, some may be stashed away as starch until the're needed. Much the same way as I store things in my sheds" Grand-dad added in a whisper.

"Not another shed!" groaned Grandma when she caught sight of this --



This is a very old drawing, by Richard, of starch being stored in an old Biddlestone shed. The shed, would you believe, once had wheels.
There's a ruined castle not far away at Harbottle. This is said to have Wheels too. It doesn't, of course but it gives me an excuse to put its picture on the next page

When Grandma said "Not another shed!"

Billie tried to hide a grin
and this made Emily giggle.

[Biddlestone, I should tell you, has only six houses but each house has lots of sheds. If you count his work-shop, grand-dad has six. Grand-ma is very anxious that there should be no more.]

This is the picture of Harbottle Castle. It hasn't really got anything to do with the story but I like it and it reminds me of Richard's shed drawing. Mary Tudor, sister of Henry VIII, had a baby here back in 1515. The Prof thinks, it would make a nice illustration of entropy in action but says that story must wait for another day .

"Carbs" said Emily, knowingly, (her mind still on starch and diets and such)

"Yes" sighed 'The Prof' "starch is a 'carb'. I like to call them carbohydrates myself because that reminds us that 'carbs' are mostly made of carbon atoms joined to water molecules. Sugars are carbs too, They all contain CH2OH"

"Do all leaves make starch?" asked Billie, thoughtfully.

"Good question" replied Grand-dad in his best professorial manner "Take spinach. Sometimes it makes starch, sometimes it doesn't. Imagine a spinach plant growing in good, moist, soil. on a warm May morning. It's growing like crazy. So fast that you can almost see it grow.. But it's starch shed is empty and the growing leaves are crying out for sucrose. They win. Nothing that is made goes into the shed.. But how about another spinach plant growing in a dry patch, unable to pick up the other bits and pieces from the soil that it needs if it is to make proteins and such for new leaves. Then it starts making and storing starch"

"The shed's are inside its chloroplasts aren't they? How do they know to start making starch?" .

"They get a message" replied 'The Prof', admiringly. "Remember what comes out of chloroplasts that leaves use to make sucrose out of?

Triose phosphates?"

.

"That's right. What's more there's a demon who controls how much comes out"

"A demon!!" cried Emily, (doing her Lady Bracknell bit)

"No, Emily" smiled'The Prof', "A pretend demon. But what he does is real enough. Offer him four molecules of phosphate and he will let four triose phosphates cut. That's enough to make one sucrose. As you know, sucrose has 12 carbons. You can write it as $C_{12}H_{22}O_{11}$ if you like and then you can see that four phosphates have been released. as the sugar is made from four triose phosphates.That's what lets it continue"

"Phew!" said Emily,

"Wow" said Billie

[Grand-dad guessed that the girl's response to all of this might have been just a shade tongue in cheek but understandably so. Anyway he is almost as keen on allusions, as he is on puns and glad to have an opportunity to use his son's artwork once again.]

This is a drawing that Grand-dad's son Richard did, long ago . The part played by phosphate in photosynthetic carbon metabolism is very dear to his heart and probably why he is till writing about it.

"However, if the sucrose doesn't get used it gets harder and harder to make. That means less and less phosphate to offer the demon. The chloroplasts can't move triose phosphates out as fast as before so they start storing it as starch"

"But do all leaves make starch some of the time?" asked Billie, .

"No, you might have been taught that at school and starch pictures are a very good way of demonstrating photosynthesis but some leaves never make starch"

"What! ,Never?" quoted Billie, (Knowing that Grand-dad was never seasick and what the Captain of the Pinafore might have said)

"No, Never" insisted 'The Prof', "and there's a very good example right here. When you come here in the Spring we have lots and lots of snowdrops. There's a big patch right next to the tree-house"

.

"We are a long way north. About 7 miles from Scotland. So, early in the year, the days are very short and cold and there is often lots of snow. However, even under nearby ever-green trees, where there isn't much light., the snowdrops do very well. Of course, at first, they rely on food that they stored in their corms, underground.. But very soon they have to start start storing food underground for next year . Not too surprising that they never store food, as starch, in their leaves."

Chapter Four

In the beginning, there be

honeycombs and archdeacons

"Grand-dad" said Billie, thoughtfully. (Billie called 'The Prof' grand-dad every now and again because, after all he was her grand-dad) " Do you remember saying, at the beginning of this story, that photosynthesis had changed the world?. I know that all animals,including us, eat plants or other animals and that without photosynthesis none of us would have anythingto eat.. And I know that plants make oxygen when the sun shines but there had to be a world to start with.
So what else did photosynthesis change?"

'The Prof' looked thoughtful too, as though he didn't know where to begin. After a moment or two he said "How old is the world?"

"Millions and million of years" chipped in Emily, not wishing to be left out of this?.

"How many millions?"

"Lots" said Emily

"No one knows for sure but its probably about 4.6 billion."

"When I was your age" added 'The Prof' (in the way that old professors do) "a billion was a million million. These days it's only a thousand million. So that's not so bad but, even so, 4.6 billion is still

4600,000,000 years

and. I find that awfully difficult to think about. I find it easier to squeeze it all into 24 hours " he continued nonchalently. "the arithmetic's very tedious so I won't bother you with it. But, when it's done, we start at midnight on the first day. Right now we would be at midnight on the following day."

"It's the bits in between" he added "that take the arithmetic"

" When did the dinosaurs live?"asked Billie

"The Jurassic, lasted from about about 208 million years ago to about 146 MYA and that works out at about 10:55 pm to about 11:14 pm" smiled 'The Prof' "but let's start at the beginning."

"We can even skip most of the first three hours that I have squeezed all of those years into. At first, our planet was like a big ball of red hot lava. Then bits would start to cool a little and form the beginnings of a crust, only to sink below the surface once again. Gradually a real crust would spread on the surface but there would be volcanoes spouting lava and ash and smoke all over the place. It would have been dark, to start with, because of all the ash and smoke.

And what about air to breathe? None that we would like. Mostly CO_2 and a bit of nitrogen. Scarcely a wiff of oxygen. Maybe some hydrogen, methane and ammonia".

Here the Prof paused for breath himself "Of course photosynthesis was going to fix that but not until 5.45 am, or thereabouts. Before that, starting soon after 3 am living things started to appear"

"What sort of things?" asked Emily.

..

"Tiny" replied the Prof.

" Where did they come from?" asked Billie.

"Out of honeycombs" replied the Prof.

Here we go again thought Billie and Emily

"Hot springs make things like honeycombs out of iron and sulphur. Millions of very tiny "cells"
Hot water, full of chemicals, flows into these cells.
Something like this could have happened back at the start of things at the bottom of oceans., The stuff iside these cells could become very concentrated
. Just what would be needed to create big molecules like proteins and DNA. Then, a skin might have formed"

"like it does on warm milk?"guessed Billie

'"And tiny balloons of stuff could have slipped out to live in the brave new world."

Here the Prof could be heard muttering to himself "Stone walls do not a prison make, nor iron bars a cage". (He had a great weakness for quotations).

"*Live* Balloons?" asked Emily, sceptically.

"The remarkable thing" replied the Prof "is, that there are very tiny things called Archaeans living happily in hot springs to this very day."

"No, Emily not Arch*deacons* , Arch*aeans* "

"What's more, their ancestors lived there 3 billion years ago . So if these tiny balloons had proteins, DNA and such, they could have become the first living things and that would have made them our ancestors too."

" But maybe our ancestors were space travellers" said Billie.

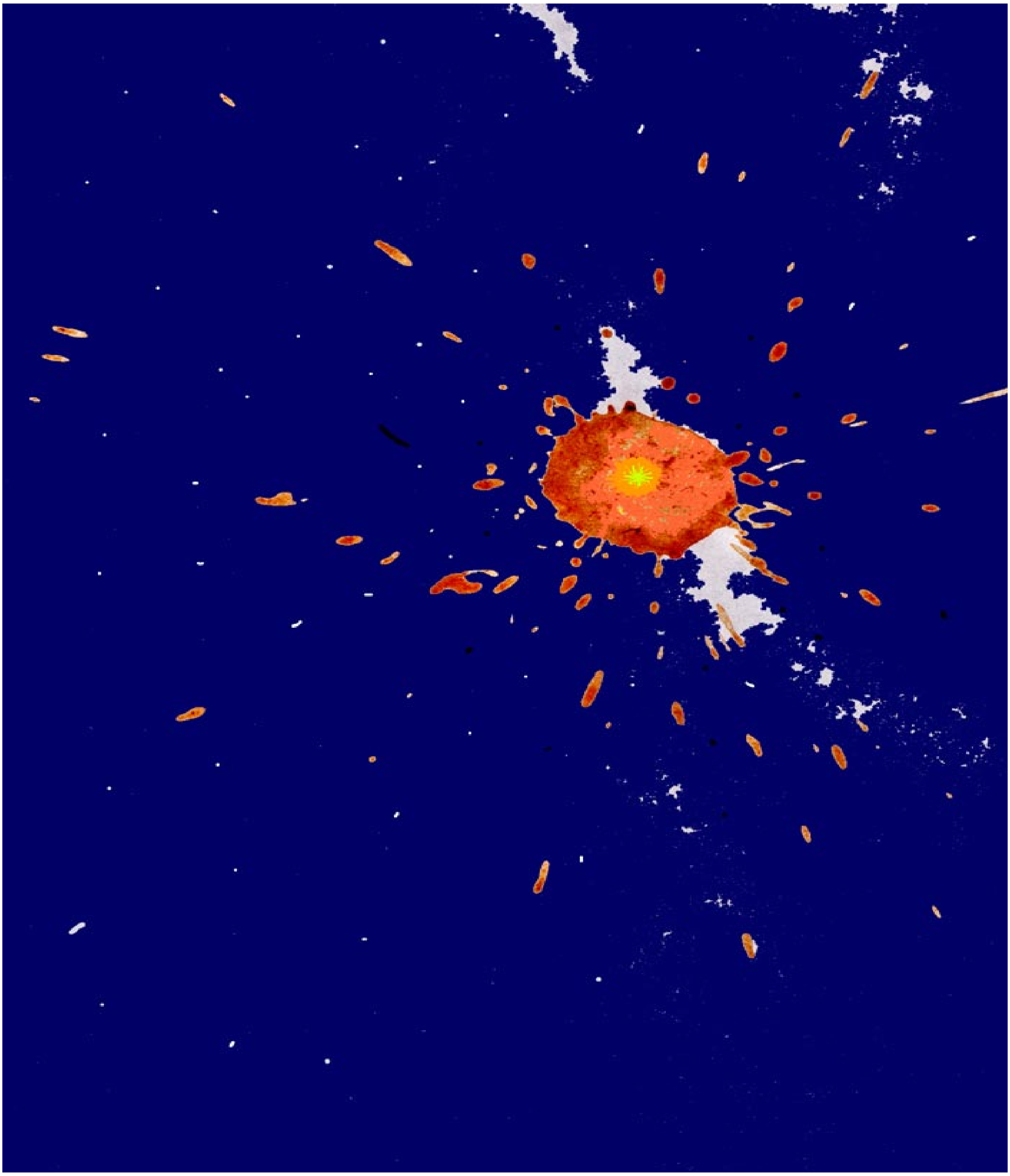
"Not impossible but life must have started somewhere because even our universe hasn't been there for ever.

"No, Emily not Archdeacons .... Archaeans

"How, asked Emily, did it start?"

"About 15 billion years ago there was a

very, very very BIG BANG!!!



" And, before you ask, no one knows who lit the match, grinned the Prof. The Big Bang. sent burning star dust flying in all directions. Much of it's still burning like our Sun and other stars. Some of it cooled and made our Earth and other planets.

No one knows how life started either. Lots of people think that God did it. Back in 1802, William Paley, son of an English priest and much respected, said that living things were so much more complicated than watches that there had to be an intelligent watchmaker.

" What do you think, Grand-dad" asked Billie.

" I was afraid you would ask that,. sighed the Prof, sometimes I sits and thinks and sometimes I just sits. What's more, that's the sort of thing that you two must make up your own minds about."

"But, he grinned, if that isn't going to satisfy you, and I can see that it isn't, this is how it looks to me. Even the smallest bacteria and such are very, very complicated. It'sawfully difficult to imagine how molecules like DNA and chlorophyll came about in the first place.

This is a picture of Grand-dad doing his 'Newton-thinking-about-the-apple' bit. He says that there is no need for you all to rush to tell him that he isn't in the same league as Newton. Just that the story keeps going on about light and Newton wrote one of the most important books ever about light a few hundred years ago

"On the other hand, he continued, it's even harder, for me, to imagine a God , or a intelligent designer, or watchmaker, or whatever, who could sit down and make such things."

"Anyway, as they say these days, let's lighten up a bit. Right now, no one knows how DNA was first made but, once it had arrived, everything else gets just that little bit easier to follow. So let's not fret too much about what we don't know and get back to the honeycombs and the Archdeacons."

"Not Arch*deacons* " cried Emily, gleefully "Arch*eans* ".

"Your fault said the Prof but you're quite right. By now I've got to an age when I have to remember that it's Minnestrone soup and not Minnesota soup."

"I like the idea of tiny Archdeacons living in honeycombs" said Billy

So do I" confessed Grand-dad " but the things that we are talking about, that look like tiny bacteria, are really Archaeans. We know for sure that are not bacteria because they have very unusual membranes containing isoprene".

"Membranes?" queried Billy.

" *Made of Isoprene?*" echoed Emily

"Skins, answered the Prof, made of rubbery stuff. Remember when we were fooling about with balloons? They have rubber skins don't they? Where does rubber come from?

"Trees?"

"Absolutely. And where might you expect to find a rubber tree?"

The girls went into a little huddle about this so the Prof whispered "Professor Challenger?" by way of a hint. Not the Lost World he added hastily but thereabouts.

"The Amazon!."

"South America!" Yelled the girls.

"That's right. That's where they came from in the first place. Made the people there very rich. Even built an opera house and got Enrico Caruso to sing there. As famous in his time as Elvis he added quickly. Then a man called Henry Whickham stole lots of seeds and now rubber trees grow all over the tropics.

By now, as you can see, the Prof was wandering again, but he continued anyway."Now we get to a hard bit. Remember when we were fooling about with the Biddlestone Eye? How it's turned by water and it makes electricity?. Further down the stream there's a little dam and, if we let the water in it run out through a turbine, that would make electricity too. Living things also have dams and nanoturbines . The dams are called membranes and they hold back bits of water called protons. At the time that the honeycombs were made, the sea contained lots and lots of protons and the walls of the honeycombs held them back.. And, if you have protons behind a honeycomb wall, you have a source of energy.

That, energy, so it seems , was used to make the sort of things that living creatures are made of. Not sugar and spice, or even slugsl and snails, but molecules made of carbon, hydrogen, nitrogen, oxygen and phosphorus. These were what the Archaeans were eventually made of many millions of years later.

That's some time after three o'clock in the morning" he added "if you squeeze 4.5 billion years into 24 hours.

“What are little girls made of?
Sugar and spice and all things nice,
That’s what little girls are made of.

What are little boys made of?
Slugs and snails and puppy-dogs’ tails,
That’s what little boys are made of

"By then the Archaeans thought that it was time that they got out a bit more, instead of sitting in their cells. And that's when they put on their rubber wet-suits and started to explore"

"Thought? sniffed Emily

"Rubber wet-suits? echoed Billie

"Artistic licence" replied the Prof "No. of course they couldn't think the way that we do. And their skins weren't made of rubber although they did contain isoprene. And they needed a skin to protect them when they went outside. Not a wet-suit, more of a bag"

A hand-bag!!!!? cried Billie, pretending to be Lady Bracknell.

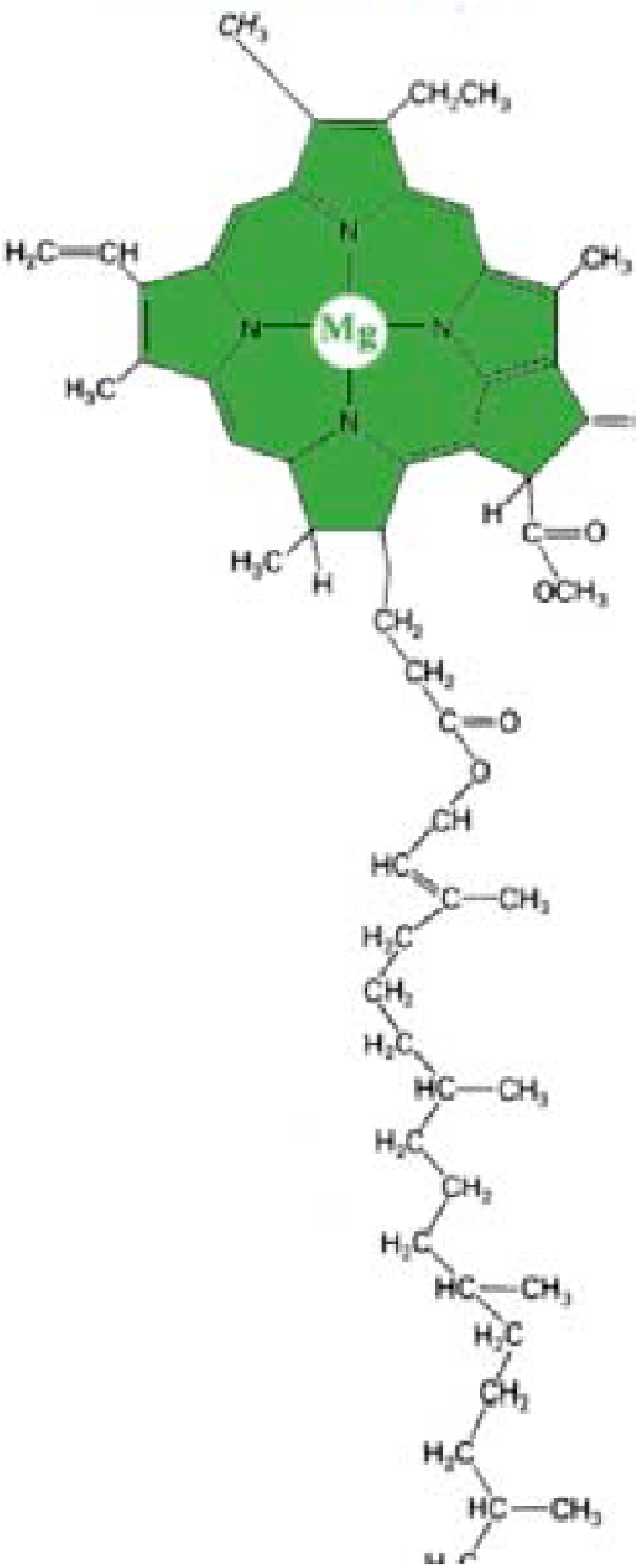
The Prof liked literary allusions too, so he just smiled and continued. "What's more there are those who think this skin eventually evolved into a thing called a thylakoid that chloroplasts have"

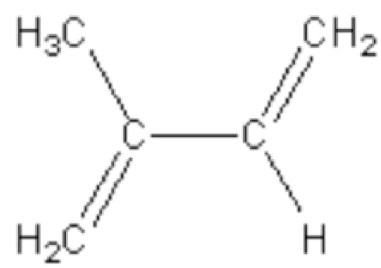
[Grand-dad had worked on chloroplasts in his youth, mainly from Spinach. He figured out how to take them out of a leaf without breaking them. Joining forces with an electron microscopist, called Dennis Greenwood, he was able to show that they only worked properly if their skins or 'envelopes' (they have two) were still intact.. That's why, when he moved to Sheffield from Imperial College in London in 1970, he called his inaugural lecture 'Chloroplasts in Envelopes' He still likes Spinach but only to eat]

" You might suppose that the outer skin of the Archaeans would have became the inner skin of the chloroplast. continued the Prof. but it doesn't seem to have happened like that. If it had, the inner skins of chloroplasts might have been made of isoprene.

Right now, in our story, it's only just after three in the morning, squeeze time, and chlorophyll hadn't been invented. Interesting though, that the Archaean skin contains isoprene and, as you can see on the next page, chlorophyll has a sort of tail made of isoprene . If you want to make something new it's often the case that you have to use what's at hand"

Chlorophyll, with “a sort of tail made of isoprene”.





isoprene

Chapter Five

A Forced Marriage or
a Marriage of Convenience?

"Seems that the Archdeacons eventually got married " said 'The Prof'

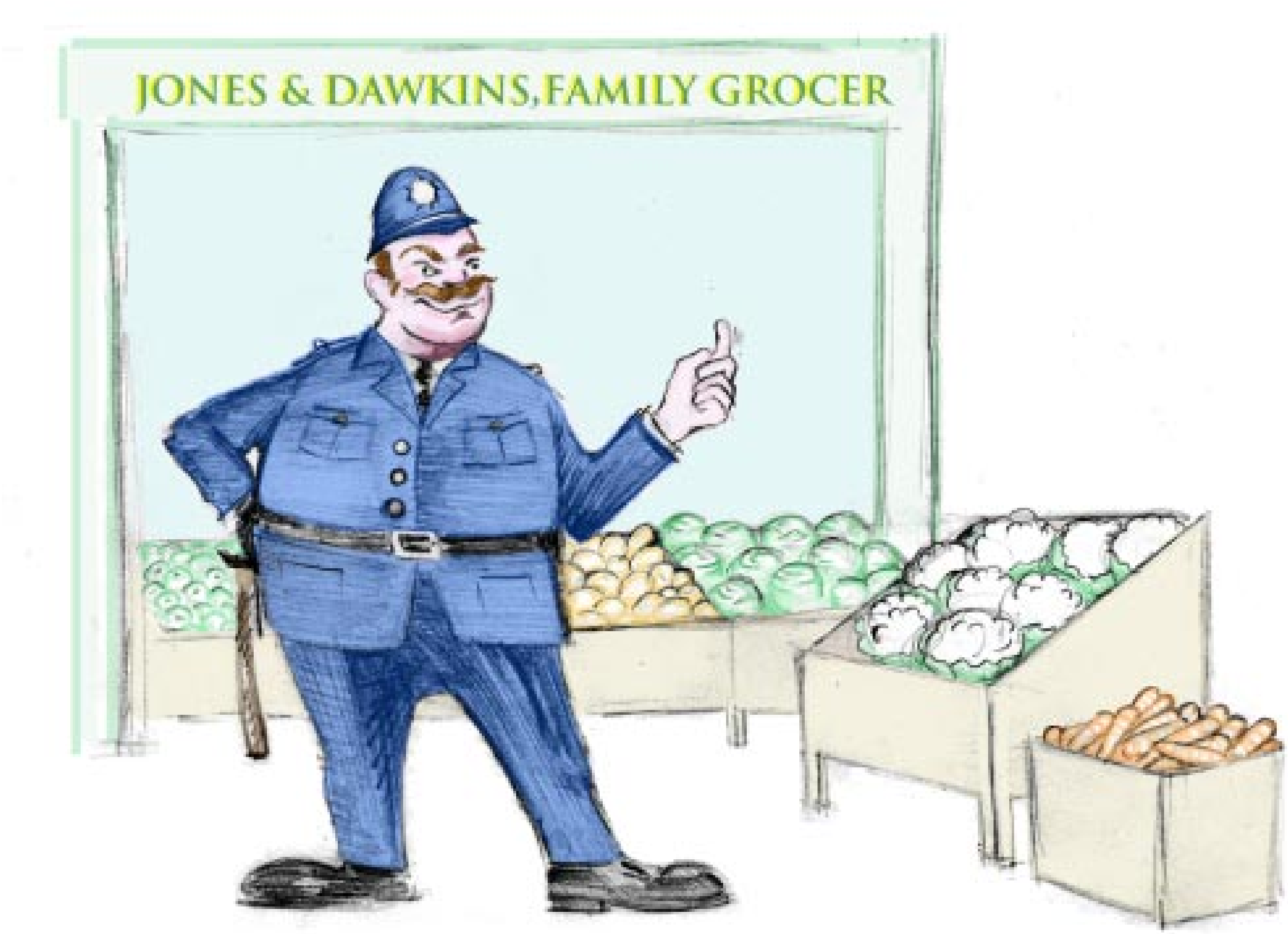
[The characters in our story were drinking tea and eating buttered toast and reflecting on where they were up to. Talk of marriages made them think of churches.
The nearest church, if you could call it that, was the Biddlestone Chapel, just half a mile away. It was built on top of what was once a Pele Tower and it's easy to see the join if you look at the picture on the far right of the next page. Northumbrians used to dash to Pele Towers when there was news of marauding Scots. Once inside, stone walls and thick doors *sometimes* kept them safe until the Scots had gone. The Biddlestone Tower was first mentioned in writing in 1410 but it might well have been there a hundred years already. A hundred years is a long time to you and me but your eye closes for about 100 to 150 thousands of a second when you blink, . In "sqeeze time' that works out at about 6,000 years. I mention this just to emphasize how difficult it is for scientists to figure out what was happening round about 21 hours ago, squeeze time.]

The nearest church, if you could call it that, was the Biddlestone Chapel

Of course the girls guessed that The Prof was talking about what the Archaeans might have been up to 3 or 4 billion years ago and that and he didn't have churches in mind when he talked about them getting married.

"Before we get on to that " continued 'The Prof "I must tell you that, when I was a student, I was taught that Kind PC Orders Family Greens Soon"

"PCs weren't invented then" said Emily"and why have you put the first letters in red?"



Kind PC orders family greens soon

"It's a mnemonic" said Billie grandly.

"It's a mnemonic said Billie grandly, to make it easier for you to remember. 'K' stands for Kingdom and 'S' for species.and so on. I once did one with Grand-dad and you can look at it here. Grand-dad says that, in his day, there were only two Kingdoms and everything that wasn't an animal had to be a plant.

"That's right " continued 'The Prof "and now it's carrying oats".

"Carrying oats?" said Emily, doubtfully.

"As in pro-carry-oats and you-carry-oats " grinned 'The Prof "Easier to remember than 'Prokaryotes ' and 'Eukaryotes',---maybe.

So by the 1970s there were five Kingdoms instead of two. There were prokaryotes. animals, plants, fungi, and protists. The last four were all 'Eukaryotes',"

"Protests!" protested Billie, tonque in cheek.

'Protists" insisted 'The Prof and, before you ask, a protist is any old eucaryote that isn't a plant, or an animal, or a fungus."

"But what" protested Billie, becoming much more serious but having warmed to the notion of carrying oats"is the difference between pro-carry-oats and you-carry-oats?"

"We're back to membranes again, said 'The Prof "prokaryotes don't have skins round their internal bits and pieces and Eukaryotes do. And you-carry-oats have nuclei and stuff".

"This is getting awfully complicated" said Emily, ruefully.

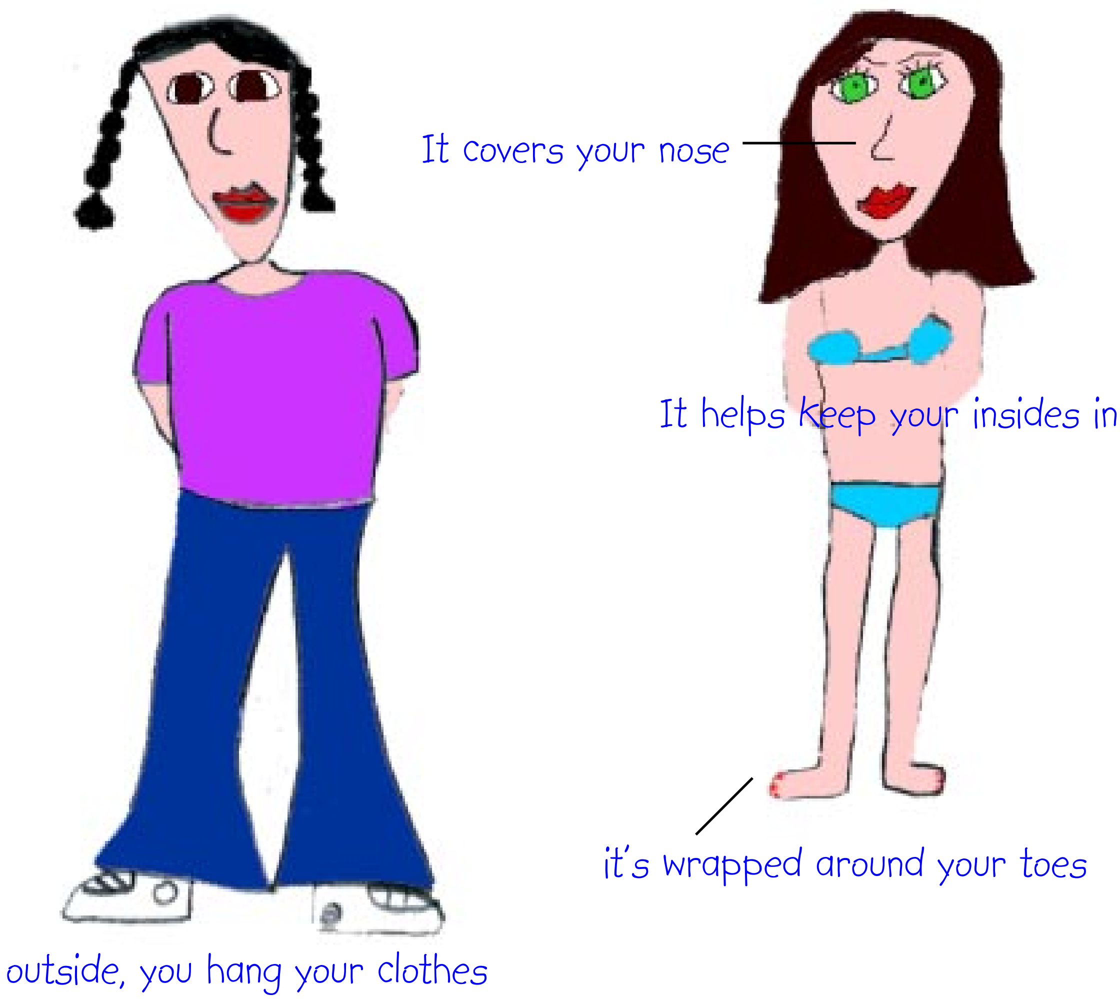
"You're right " sighed 'The Prof "and it gets worse but it'll soon be done and then we can move on.

Much to everyone's astonishment, back in the late 1970s, a man called Carl Woese. who happened to be born just a month before Grand-Dad, came up with a whole new lot of protists called ...

"Archdeacons!" yelled Emily,

"Archaeans" groaned Billie

You Gotta Have Skin



"prokaryotes don't have skins round their internal bits and pieces and Eukaryotes do.....".

You Gotta Have Skin
(Alan Sherman)

"You gotta have skin,
All you really need is skin
Skin's the thing that,
if you've got it outside
It helps keep your insides in
It covers your nose,I
And it's wrapped around
your toes
And inside it you put lemon
meringue
And outside, you hang your
clothes
Skin is what you feel at home in
And without it, furthermore
Both your liver and abdomen
Would keep falling on the floor
(And you'd be dressed in your
intestine)"

back to page 77

" Now there are facts " continued 'The Prof, (going off in a new direction, as he so often did) "and there are theories. When I was in junior school, a teacher asked why an apple falls to the ground from a tree. Because it was heavier than air, I thought, but she said it was because of gravity and Newton and all that stuff. She was right of course but that was the first that I had heard of gravity or Newton.

"You were wrong" said Emily, just a shade triumphantly.

"'Fraid not. Just different ways of looking at things. If Newton's apple had fallen into a pail of water it might have floated. A balloon full of hydrogen would go up"

"Can we play bob-apple some time?" asked Billie

"Come Halloween, we ought to do just that" smiled 'The Prof but forgive me if I to get back to facts and theories, Evolution is a fact *and* a theory.. We know for certain that it happens and we have a good idea how and why it happens. For example we know for certain that what we call the Jurassic lasted from about 208 to about 146 million years ago.

" In 'Sqeeze Time' that's like starting at about five minutes to 11 pm and lasting for only twenty minutes or so. We can only guess about is what happened in the wee small hours"

"Poor dinosaurs" sighed Billie "here and gone in twenty minutes".

"Since I first heard about the archdeacons" continued Grand-dad, forgetting for a moment that it was about time that he started calling them the archaeans "I've got to like them and they *may* have been our ancestors and the ancestors of *every* living thing. *If* they came first, they must have given rise to the bacteria and then gone on to marry them. Sounds a bit odd, I know."

"I'd sooner marry a duckbill platypus" said Billie who, you should know, likes Tom Lehrer.

"Must have had an Oedipus Complex" said Emily, knowingly.

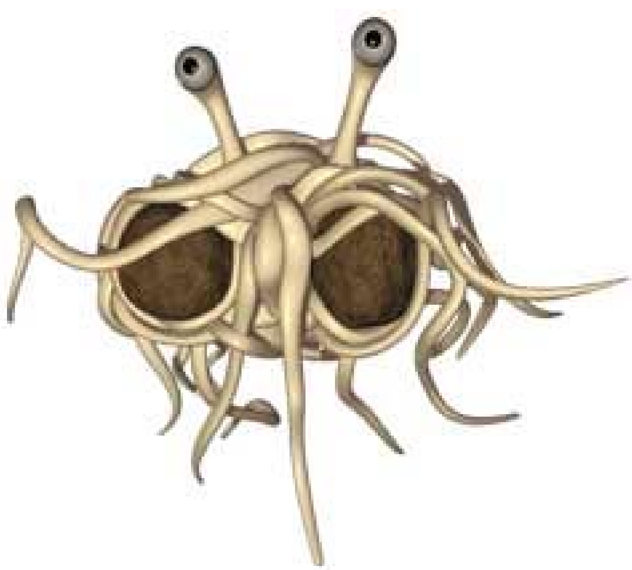
The Prof gave the girls a quizzical glance and continued....

" Recently, a man called Hartman has come up with a new idea. He thinks that there were things called chronocytes *They* came first. Then *they* gave rise to the archaeans and the bacteria. Then they ate them." .

"Ate them?" shreiked Billie

"Ate them!" echoed Emily

"Sort of" soothed the Prof. "Engulfed them,. That's how the you-carry-oats *may* have started. If that's how it happened I suppose you could call it a forced marriage.



This is not a picture of a chronocyte but
it made the girls wonder if it could have been

"And the children of the marriage" went on the Prof "have *stuff* that they inherited from the chronocytes *and* the bacteria *and* the archeans. That meant they could have skins round their internal bits and pieces and that makes them the......"

"Eukaryotes" cried Billie confidently, having taken a quick peep at the top of the page.

"And the Eucaryotes make up four kingdoms" said Emily, not wishing to be left out and having glanced at page two, "the animals and the plants and the fungi and protists"

" And the protists" added Billie, for good measure" are you-carry-oats that are neither plants, animals, or funguses"

. "In the best circles" said Grand-dad, professorially "Funguses are called fungi but, apart from that, I wish I could remember it all as well you do. Used to be all a lot easier in my day".

" Before we continue" said the Prof "we'd better have a word about respiration. Tell me what you know about that"

"We breathe in air and breathe out carbon dioxide " said Emily

"And ?' asked the Prof, turning away as he did so and breathing on the nearest window pane (which promptly misted over).

"Steam?" suggested Billie, just a bit doubtfully

"Water vapour" said Emily, rather grandly.

"And what do we do with the oxygen in the air that we breathe in?' asked the Prof.

"We use it to burn sugar to give us energy, don't we?" said Billie.

"What well informed young women you are." said the Prof, approvingly. "Leaves do much the same-

"They don't breathe like us, of course. The oxygen just slips in through the holes in their leaves. It's used to burn sugars to provide energy. Not fierce burning with flames like it would be on a fire but in a quiet sort of way just like we do. It's a bit like photosynthesis in reverse. It goes on in little bodies, called mitochondria. Like chloroplasts, they have two skins and contain the nanoturbines for making ATP that we've talked about"..

" Back in 1953" he added, nostalgically "I did experiments with mitochondria from castor oil beans"

"Castor oil beans!" exclaimed Emily.

"Yup" said Grand-dad "At Purdue University in West Lafayette, Indiana". (Here, much to their surprise, he burst into a verse of "Hail, hail to Old Purdue" before getting on with the story).

"Almost all living creatures have mitochondria but I happened to be working with castor beans at the time"

"Before we continue" said Billie thoughtfully, (and in her best answer-me-that fashion) "What did the Archdeacons, I mean Archaeans, have to eat?. You've told us how green plants make the food that we eat but there weren't any green plants 4 billion years ago, or whenever, were there?"

"Very perspicasious" smiled the Prof, "Right to the stomach of the matter, you might say. All we can do is to engage in a bit of educated guesswork.. We can never be sure exactly what creatures that lived about four thousand million years ago did for a living but we know what their modern anscestors are doing right now"

"Have I told you about black smokers?

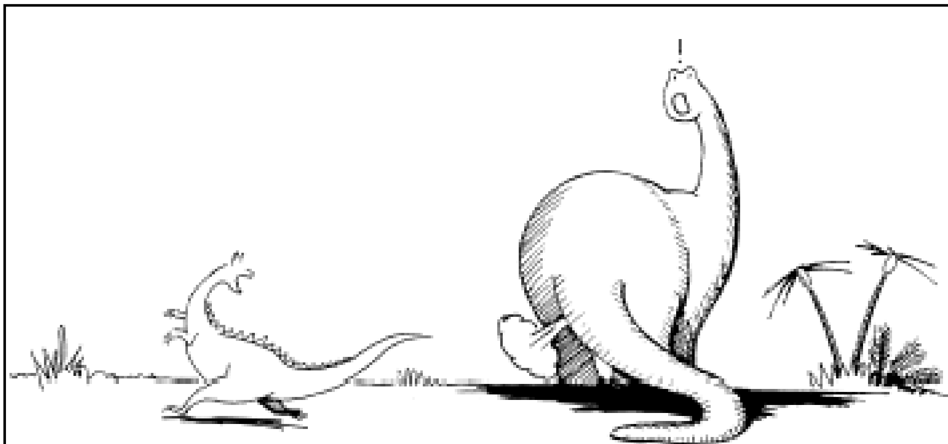
"The're are going to stop smoking in pubs" said Grandma "and not before time"

"Quite right "said the Prof, "but the blacksmokers that I'm thinking about are a bit like hot springs on the floors of oceans. Full of hydrogen and stuff. Archaeans live in cells in their walls"

"And some of them eat hydrogen and fart methane"

"You oughtn't to use words like that" said Grandma.

" Chaucer did" said Grand-dad " used it all the time. Good old English word. Anyway, all manner of creatures, large and small, have been farting methane ever since the archeans first got round to it. What's more it gives me an excuse to use another of Richard's old cartoons."



"Some of us fart a lot and some of us fart a little but, whatever anyone tells you, there is no-one, not even the Queen, who doesn't fart at all."

"I'm afraid "said the Prof, "that I'm going to have to get into oxidation before......."

"....we continue" finished Billie

"You know me too well" agreed the Prof, "and there really is no escaping it. . First, a word or two about chemical bonds wouldn't go amiss either"

"No need, here, to attempt to do a Linus Pauling. Enough to remember that it takes energy to break bonds like so

Breaking bonds takes energy

and, energy being what it is, you get it back if you make bonds by joining atoms together".

(Whereupon, always the one for a practical demonstration, Grand-dad lit the pile of wood that was conveniently at hand on his *barbeque*)

"Yow know, of course" said the Prof, "what the wood in those logs is mostly made of?

"Carbon" said Emily

"And what does it becomes when it's burned?"

"Carbon dioxide" said Billie

"Absolutely" said the Prof "and when you burn wood you get the energy out of it that photosynthesis put there in the first place. The energy started out as light, then it became electrical energy. That was used to break bonds in water, the hydrogen was passed on to carbon dioxide and, before you could say Andy Benson, you have chemical energy in the shape of wood"

Burning C, to get CO_2, is a nice simple example of a oxidation. So is burning sugar from your food to get the energy you need to do everything. That's what we call respiration. The energy is released in small, manageable packets.. No big flames but, as far as humans are concerned, keeps our bodies at a very constant 36.9 degrees Celsius, 24/7/365.

(Writing 24/7/365.is Grand-dad's way of saying that he's familiar with modern parlance but the truth of the matter is that he's losing an unequal battle)

"When" continued the Prof, "you burn logs on a fire you get very little ash but, if you stop to think about it---"

---what is left over is bigger than what was there was to start with. It looks smaller, at first glance, because we usually forget to count the CO_2 that goes up with the flames. But, if we do think about it, CO_2 is bigger than C, however we look at it"

[While the Prof is holding forth about oxidation and reduction we should note that Joseph Swan is one of his all-time scientific heroes. Swan figured out how to stop an electric light filament becoming oxidised and burning itself to bits. He demonstrated the world' first incandescent electric light bulb in Sunderland back in January 1879, some 10 months before Edison. That's how Cragside, just 10 miles from where Billie and Emily are chatting in our story, came to be the first house in the world to have electric lights]

"That" the Prof said, contently (as though introducing an old and much respected friend) "brings us to reduction"

" If you oxidise C to CO_2 it becomes bigger. If you reduce CO_2 to C it becomes smaller. Maybe that isn't why it's called reduction but, in any case, there's a lot more.......

"--to it than that," finished Emily,

"---than that" echoed Billie

"Absolutely" said the Prof, not to be put off his stride "here's what you should remember"

" If something gets oxidised something else has to be reduced. Adding oxygen or removing hydrogen is an oxidation. Adding hydrogen or removing oxygen is a reduction That may seem obvious enough if you happen to be an Archaean and you reduce CO_2 with hydrogen so that it becomes methane like so;-

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

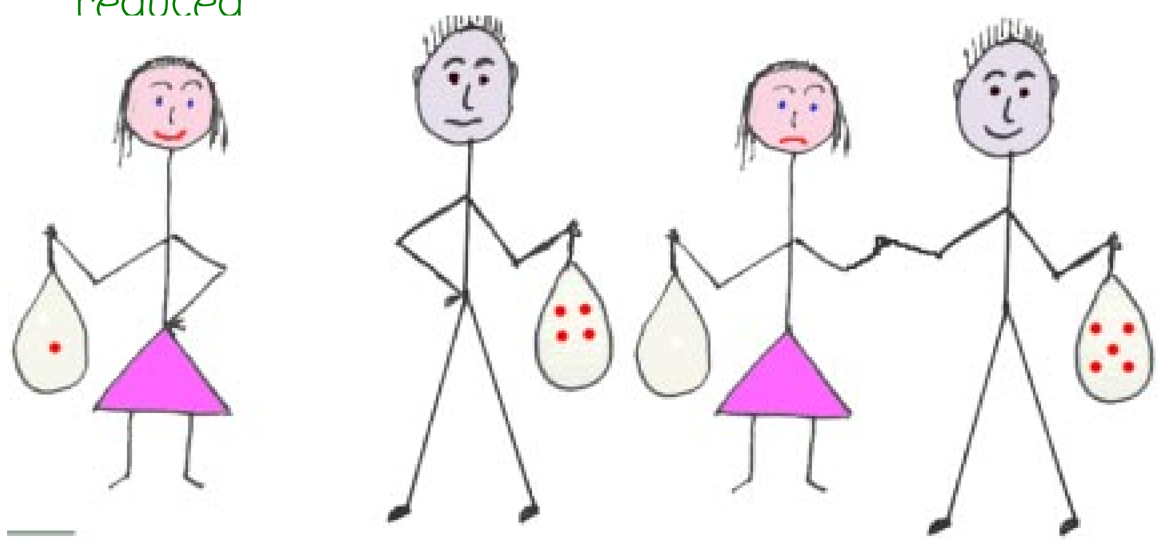
The CO_2 is reduced to methane, and some of the hydrogen is oxidised to water. However, the rest of the hydrogen has also been oxidised by being added to the carbon. The electrons that these hydrogens once had to themselves are now cozying up to the carbon. In the end it all has to do with electrons being moved away from what is being reduced towards what is being oxidised".

"Not what you could call easy" said Billie

"Not at all easy," added Emily, for good measure.

"Clear as mud" thought Grandma (who had been listening in the background).

"Look at it this way" said the Prof, "new bonds, like those in methane, involve sharing electrons between hydrogen and carbon but the carbon gets the lion's share. Electrons move from the hydrogen, that is being oxidised, a little nearer to the carbon that is being reduced"



Grand-dad did this drawing so its not very good. He says that you have to remember that the man in this picture (the carbon) should really be holding hands with four hydrogens in order to become methane and finish up with all eight electrons nearest to him

"Does carbon always get the lion's share of electrons?"

"No" said the Prof, admiringly, "depends on what it's bonding with. Electrons like cozying up to oxgen more than they do to carbon. In CO2 for example, it's oxygen that gets the lion's share"

"We'll have to get back to this shortly but right now let's get this marriage over and done with. It's all very much to do with how life started in the first place. Once upon a time, when I was young, there was this notion of some sort of primordial soup in warm ponds. Now, people like Mike Russell say that, at the beginning of things, the land would have been far too uncomfortable and unstabl.e for this to happen.

Much more likely that life started in ready-made cells, like honeycombs, formed by purely chemical reactions, involving iron and sulphur, as water seeped into the floors of oceans. That, as we talked about in chapter five, may have been were the Chronocytes, the first living organisms, were formed. Where the Archaea came about, where they hung out, and from where they eventually, slipped out."

The nice thing about the archaeans, apart from sounding like archdeacons, is that their descendents are still --

--with us and we know quite a bit about what they can do now. On the other hand, the Cronocytes only exist as an idea even if it does seem very likely that the Archaeans and the Bacteria must have had a commom ancestor.. Like Cronus, the mythological God after whom Hyman Hartman named them, the Cronocytes may also have swallowed their children"

"Sounds creepy" said Billie

"Hard to be sure about who ate what or who married whom said the Prof, anxious not to lose the plot , but the 'Hydrogen Hypothesis' proposed by Martin and Muller seems to have a lot going for it. They say that the Archaeans and the Bacteria got together to form the first Eucaryotes"

.

"This is making me dizzy," complained Emily,

"I think that you shoud all stop for tea" said Grandma and, as an afterthought, "strange name that, to give a child, don't you think?"

"I'm not sure who married who now" said Billie

"Or who ate who" added Emily.

"Not sure I do" said the Prof, "don't think that anyone knows for sure, yet. But, I tell you what---."

"Bet its got something to do electrons and protons and stuff" said Billie

"Certainly has." said the Prof, "What do we have in common with Archaeans and Bacteria and castor oil beans and Prince Charles and real archdeacons for that matter?

"Has to be nanoturbines" said Emily.

"Driven by protons" added Billie, triumphantly.

"Tea's going cold" yelled Grandma

"Would you believe" said the Prof, "that the Archeans invented the wheel?"

"Here we go" said Emily

"Me neither" said the Prof, except in a manner of speaking but *if* the Archaea that lived three and a half billion years did what their descendents are doing today they must have had both a wheel and a cycle"

"Hard to have one without the other" ventured Billie

"True" said the Prof, "so lets start with the wheel. "Apparently the present Archaeans have pretty much the same nanoturbines as the rest of us. If you remember, electron transport is the driving force. That's what causes protons to build up behind a membrane like water behind a dam"

"An isoprene membrane?" asked Billie, thinking back to rubber and the Amazon and Caruso and all that stuff.

"That's right" said the Prof, anxious to get in one more word (or two) before tea. "unlike most living creatures, the Archaeans have isoprene membranes but they do the same sort of job that ours do."

"Some of the modern-day ones use hydrogen to reduce CO_2 to methane. They are called 'Methanogens' and they make some of their ATP pretty much the same way as we do by holding back protons behind membranes and then letting them escape by turning nanoturbines".

"Like we make electricity" said Billie "by holding back water behind dams"

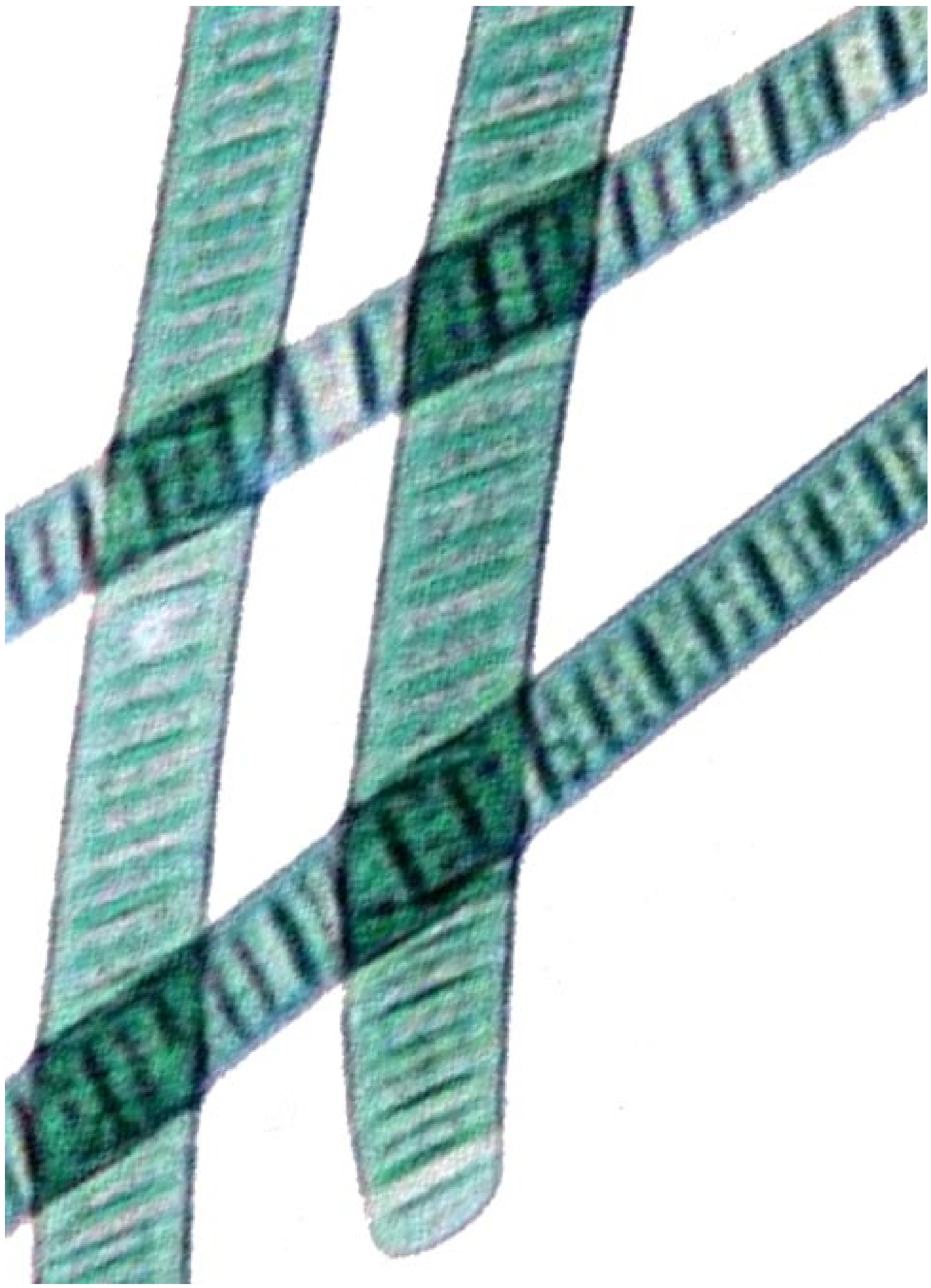
"and letting it out through great big turbines" added Emily, for good measure.

"You've got it" said the Prof, " and I bet the first ever Archaeans learned how to do that very soon after the beginning of things".

"Let's go and have our tea before it gets cold."

Chapter Six

The Blue Greens

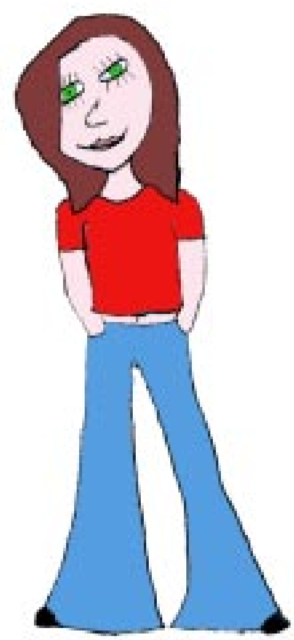


"At the very beginning of this story" said Billie " you said that it would be about how green creatures had changed the world "

"Just so " said the Prof, taking pleasure, as always, in the opportunity to use yet another literary allusion

"But" insisted Emily, "we're into chapter six already..."

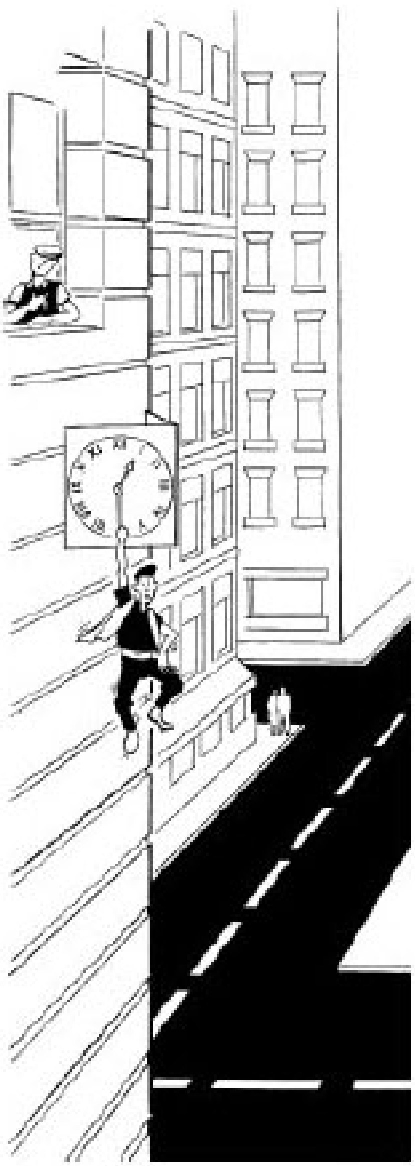
"...and look at me now " continued Billie, "I was nine when we started and I'm eleven now . At this rate I'll be a teen-ager before we are finished."



"....and" added Emily, "we're still on about archdeacons marrying bacteria and we haven't even got to the first green things yet."

"True" said the Prof, "but Rome wasn't built in a day and---"

"In squeeze time it was" said Billie.

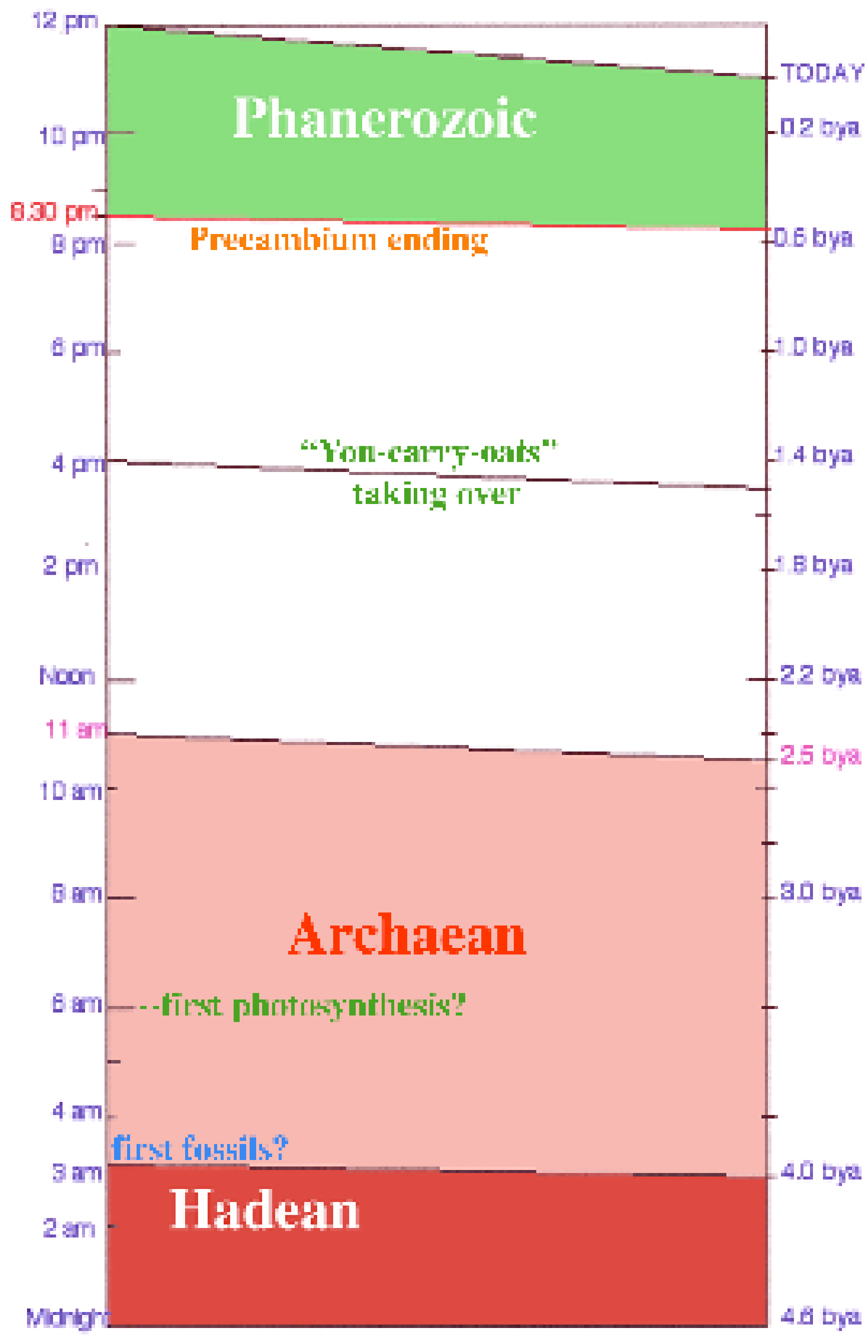


"Hang on a minute" said the Prof, "I dare say that we may have got a bit carried away about that wedding but there were green things long before there were eucaryotes. Let's just take a peep at where we have got to in squeeze time. If you ask 'Google' when the 'you-carry-oats' appeared you'll see that most people who study these things would put it at bout one thousand five hundred million years ago. That's about 4pm squeeze time. The first green things, on the other hand _may_ have been around as early as 6.am".

"What's for sure is that they were all doing there stuff round about the middle of the squeeze time day a couple of billion years ago.

I've put a sort of chart on the next page to remind us where we're at and , as you'll see, dinasours were still so far in the future that they don't even get a mention yet....

Sadly, this chart won't lead you to buried treasure but it will show you the relationship be between geological time, ' squeeze time' and buried fossils



...and don't forget that there was photosynthesis, of a sort, even before there was chlorophyll"

".Here we go again" groaned Emily, "don't tell us that there's more than one sort of photosynthesis"

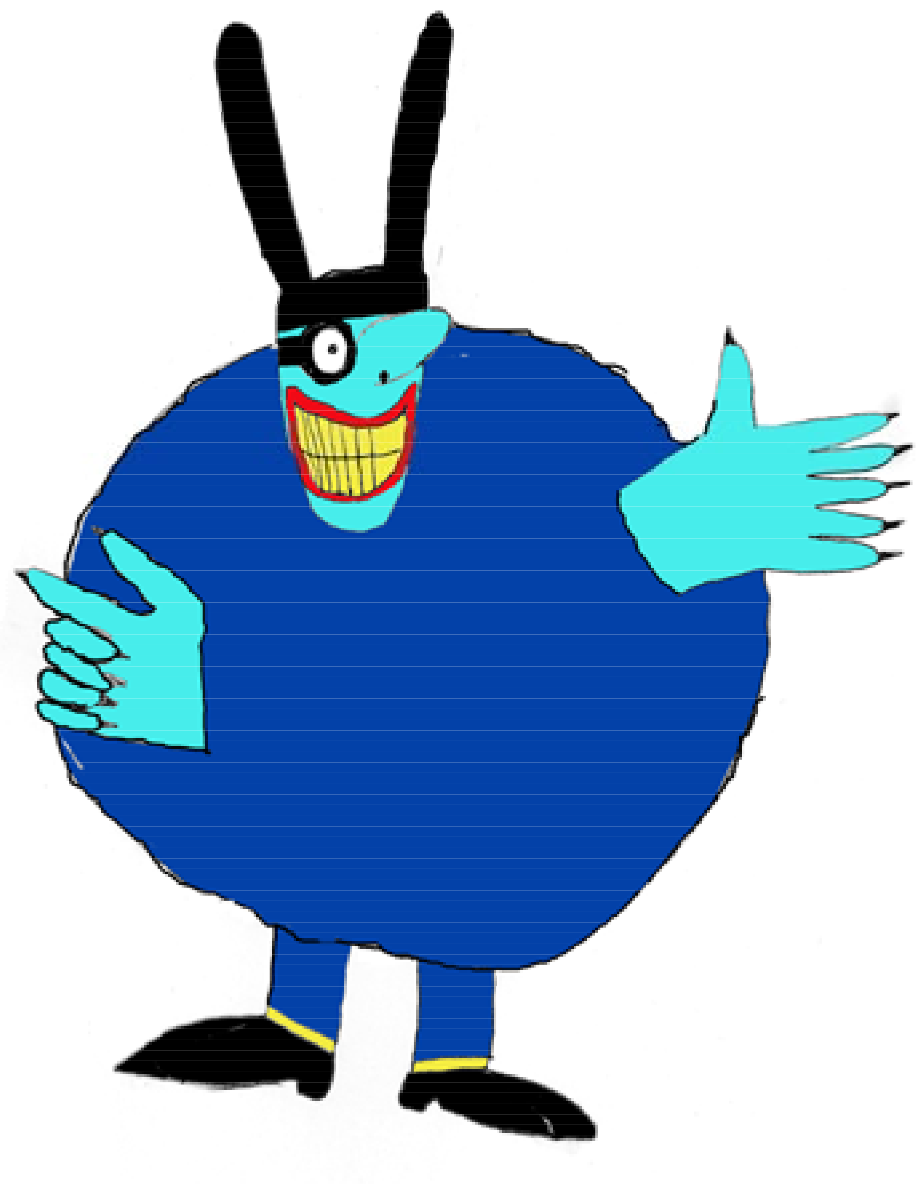
"Oh yes" said the Prof, "and, these days, molecular biologists, who spend all their time looking into DNA and such, tell us that the very first sort of photosynthesis may have been started by purple bacteria, maybe using hydrogen instead of water.

"But" protested Billie " at school, they tell us that photosynthesis needs chlorophyll and they never mention any other sort"

"That's probably because they haven't got a lot of time but you can take it from me that when the 'Blue Greens' learned how to split water, that was what really changed the world out of all recognition. They added the hydrogen from water, to CO_2, to make what they needed, and released the oxygen into the air. That's what changed things."

"The Blue Greens" said Emily, dreamily "remind me of the Blue Meanies"

" Me too, I'll draw one for you" said Billie.



And here, good as her word, is what she drew

[It might be noted here that, long ago, Grand-dad was once a small part of what was sometimes called 'David Hall's Flying Circus'.
That took himto the far corners of the Earth where no-one had ever heard of Margaret Thatcher. But, when he said he was from the north of England, everyone started to sing 'We all lived in a Yellow Submarine']

"The Yellow Submarine was once the best known song in the whole world, or so it's said." added the Prof.
"Do you remember what the Blue Meanies did, as well as turning everyone into statues, when they attacked Pepperland?"

"Stopped the music?"

"Drained all the colour out of the world?"

"Right on both counts" said the Prof, "and you could say that the Blue Greens did the very opposite, within a few million years or so.

I don't think that we could hold them responsible for present-day music but there's no doubt at all that they brightened the world up a lot."

"The world must have had some colour in it before the Blue greens got started" said Emily, "can't just have been black and white"

"True" said the Prof, " but not much. Perhaps a bit like the surface of Mars is today but with oceans"

"Wasn't the sky blue?" asked Billie."and isn't it the blue sky that makes the sea look blue?"

"O.K" said the Prof, " so the world did have some colour but not nearly as much as it was going to have. As a matter of fact I've been told that Mars has a deep blue sky when it isn't full of dust. Our blue sky has to do with light being scattered by our atmosphere and Mars doesn't have much atmosphere at all. So maybe that's why the Mars sky is a deeper blue"

"Anyway, at the time that we are thinking about now there weren't any living things on the land so it must have been a bit colourless before the first blue greens arrived"

"I've been meaning to ask " said Billie, ('who had a good idea where this might be leading)."why leaves are green?"

"Or why the cyanobacteria" said Emily, "came to be bluish green, for that matter"

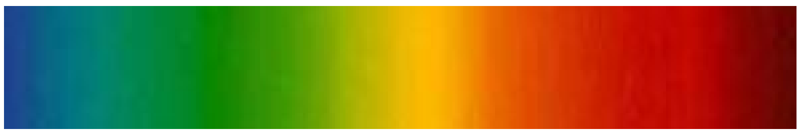
[As you will note, Emily had concluded that it was about time that we started to address the Blue Greens by their proper name]

" Why leaves look green today" said the Prof, "is a lot easier to explain than how they became green in the first place. They look green because..."

"'....they contain chlorophyll" said Billie, tongue in cheek.

"and that's green" added Emily with a touch of finality.

" Can't deny that" said the Prof, "but you must remember that chlorophylls, or leaves, or whatever, only look green because sunlight is a mixture of all the colours of the rainbow, like this.



And, what you learn at mother's knee, is that leaves look green because they contain chlorophyll. That absorbs a lot of red and blue light but hardly any green light. So, leaves reflect green light and also let green light go straight through. So they finish up looking green. But there's a bit more.... "

"'....to it than that" said Billie, sharp off the mark, as usual.

" What we have to remember" said the Prof, as though he hadn't heard Billie, " is that leaves contain other pigments, such as carotenoids. That's the stuff that makes carrots orange and help leaves go fancy colours in the autumn. They absorb some of the green light that the chlorophylls miss"

"Then why do leaves look so very, very green " said Emily, never one to miss a chance to score.

" Two reasons" said the Prof, " first there are more green photons arriving from the sun than any other sort so, although there aren't all that many that get reflected or pass straight through, there are still quite a lot.. And, as it happens, the human eye detects green photons better than any other sort "

"'So they look greener to us than they might look to a cat or a frog " said Billie.

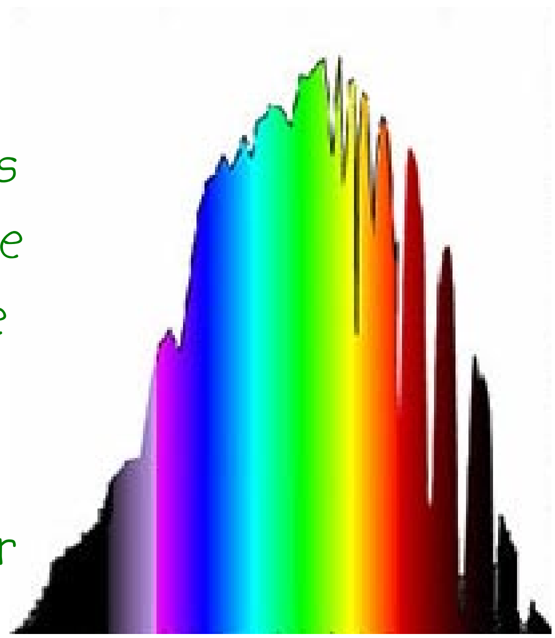
" Quite possibly" said the Prof, "but I'm not much into frogs and cats so I can't say for sure. However, since we've mentioned photons again, lets take a look at photovoltaics".

"That's to do with photoelectric cells isn't it?" said Emily,

" That's right" said the Prof, " You _are_ well informed. They might provide us with much of our electricity, some day, if we're lucky "

"'My Dad" said Billie."'says he would buy shares in indium if he could afford it"

" Smart man, your Dad" said the Prof, "They reckon that the photoelectic cells of the future will contain indium so that they can catch all the photons that the Sun delivers to Earth.



Here is a picture of the protons that arrive at the surface of the Earth.The higher the peaks the bigger the number of protons and, as you can see, there are more green ones than any other sort"

" Green leaves catch and use more of the green photons than some textbooks give them credit for. What's more some of those that get through the outside parts of leaves can be caught and used by chloroplasts further inside. And, of course, what arrives at the surface of leaves growing under trees wouldn't include as many red and blue photons because the tree leaves would have grabbed some of them first. One way and another, leaves catch just about everything that's going"

" Long, long ago he continued, nostalgically, I used to use photocells to show students what the photoelectric part of photosynthesis was all about. I dare say that I could show you both now if I could lay my hands on a couple of bits of platinum to use as electrodes 'cos I still have the self same photoelectic cell in my workshop.

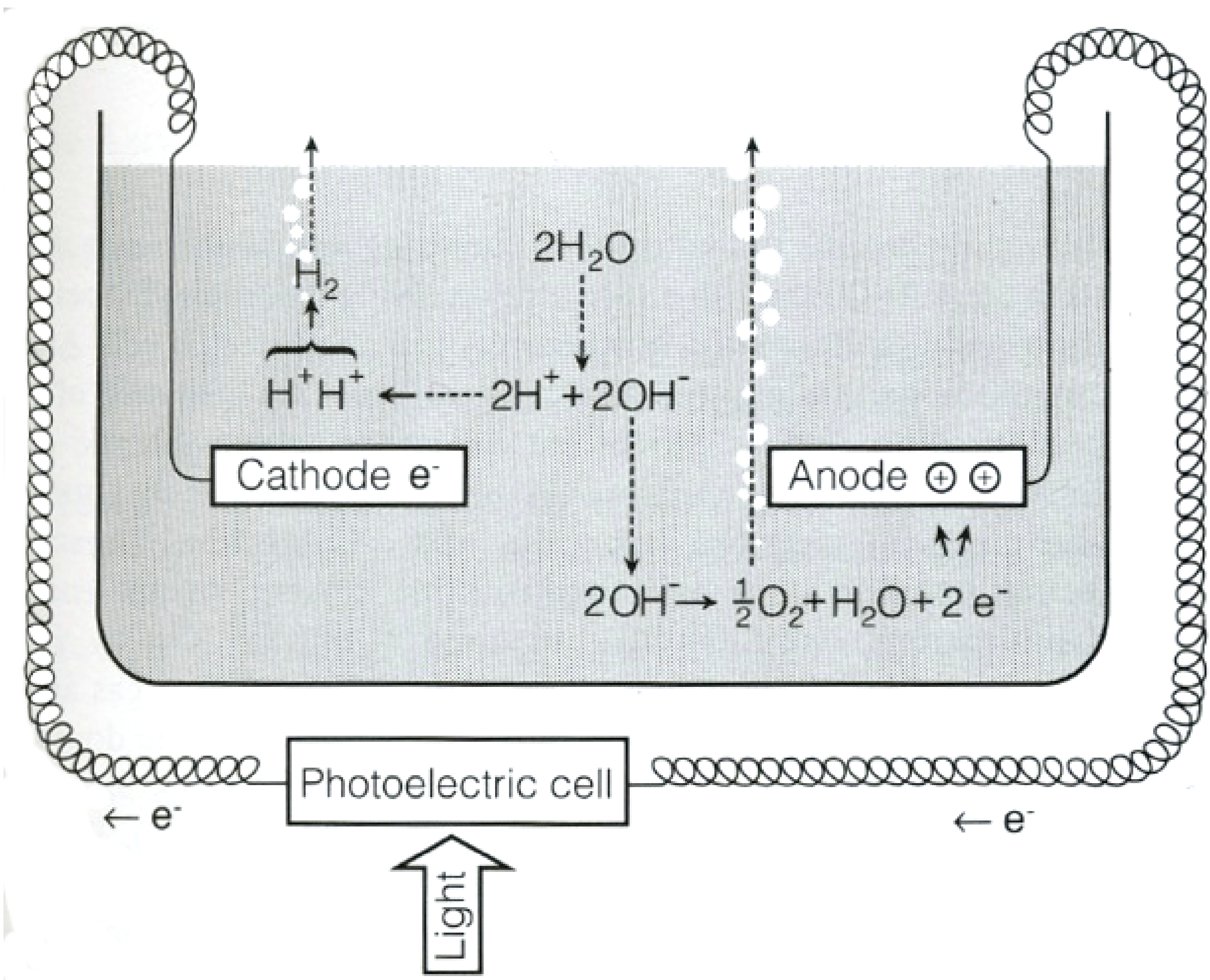
Do you remember, back in Chapter Two, how we fooled about dropping stones from the treehouse on to a see-saw to make a ball leap into the air?

"Certainly do" said Billie."' the stone was a pretend photon and ...."

"......the ball was a pretend electron being kicked up hill wasn't it?" said Emily, anxious not to be left out of yet another page.

"Well what I used to show students, was a sort of pretend antenna made of photoelectic cells, a slide projector as a make-believe sun, a beaker of water, two pieces of platinum wire to act as electrodes and some ordinary copper wire to complete a circuit. I've put a drawing of it on the next page"

" Here is what I showed them" he continued, nostalgically



"a photoelectric cell busy splitting water into oxygen and hydrogen. Photons, from the light, kick electrons out of the photoelectic cell This leaves holes that are filled by electrons from the water. These find their way back to the photoelectric cell along the curly wire. In other words, electron transport, just like that caused when photons hit chloroplhyll antennae"

"Can you remember whether electons are negative or positive?"

"Negative" said Billie confidently, having taken a quick peep at page fifteen, to make sure.

"So what will the cathode in the picture be when electrons turn up there?"

"Negative too" said Emily

"And what about the anode at the other end of the curly wire. It's losing electrons. So it will be?"

"Positive" said Billie

"Absolutely" said the Prof. So, now we've got water surrounding a negatively charged cathode and a positively charged anode. Even when it's left to itself, H_2O seperates a little bit into H^+ and OH^-. So now the hydrogen ions, H^+, move towards the cathode and the hydroxyl ions, OH^-, move to the anode. And, when two hydrogen ions pick up a couple of electrons from the....

....cathode they become a hydrogen molecule. That's why there are bubbles of hydrogen coming off the cathode in the picture. And at the anode..."

"There are bubbles of oxygen"

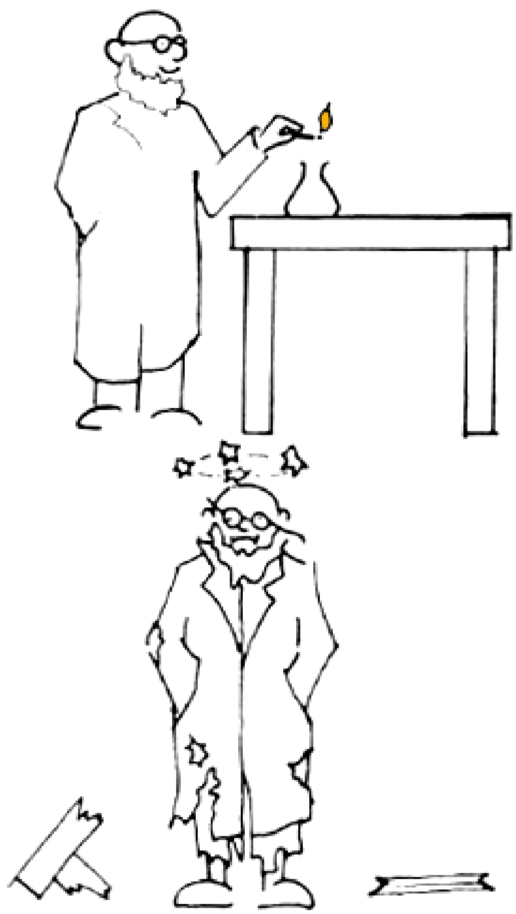
"Because two hydroxyls have given their electrons to the anode and joined together to make...."

"Oxygen" like I said, interrupted Billie, triumphantly

" By George, they've got it!,
By George, they've got it," yelled the Prof,
unable to resist doing his Henry Higgins bit.

"Now suppose that the bubbles were collected in one test-tube full of water until all the water was pushed out and the tube was full of gas." said the Prof. " There would be exactly twice as much hydrogen as oxygen wouldn't there?"

"Because water's H2O and they all came from water." agreed Emily, after a moment's thought.



"And this picture,." continued the Prof "shows what could happen if you put a match to it. Pure oxygen makes things burn very well and the oxygen is so keen to combine with the hydrogen that it does so very quickly. All of the electrical energy that was trickled into water, to seperate the hydrogen from the oxygen in the first place, comes back with one big bang

It's all a bit like photosynthesis and respiration. Chloroplasts use the Sun's energy to split water into hydrogen and oxygen. They pass the hydrogen to CO_2 to make CH_2O and stuff. Then animals eat the plants, or other animals that have eaten plants. Eventually the hydrogen in the CH_2O is slowly passed back to the oxygen and energy is released.

But this way it's trickled out, like it was trickled in."

"I think that we've lost the plot" said Emily, "You were going to tell us why leaves became green. You've told us why they look green now but not….."

"Why they became green in the first place" added Billie, " I 'spect the blue greens started it all but why green?"

Billie and Emily start looking for the lost plot

The Prof, gave the girls a quizzical look that might have meant that he knew that these two young women weren't going to let him get away with anything " Well there are several ways of looking at it. It can be argued that Evolution tried this and that and, in the end, it turned out that chlorophyll was the only possible molecule that could do the job. Along the way, the fact that this was all happening beneath the sea......"

"In a yellow submarine?" interrupted Emily, tongue in cheek.

but the Prof was very familiar with these diversionary tactics and was not to be deflected.

"The fact that this was all happening beneath the sea probably had a lot to do with it" he continued "and I'm all for the notion that, once a problem has been solved, Evolution continues to use the same bits and pieces whenever it can".

Chapter Seven

The eyes have it

"I still think that we've lost the plot" said Billie " when you first told us about those nice Archdeacons everything seened straight forward but I'm not sure where we are now."

" The Archaeans are our ancestors aren't they" added Emily, ."and you could say they are the ancestors of *everybody* and *everything*, couldn't you?

"In a manner of speaking" said the Prof

"And the Archeans married some early bacteria and that's how the blue greens came about ?"

" Remind us where the chronocytes came in"

"Well" said the Prof, in the way that Professors have " none of its what you could call straight-forward.

There's that famous biologist from M.I.T, name of Hyman Hartman who has revived this idea that there were things called chronocytes that came first"

" Chicken and egg?'

"Sort of" said the Prof, "and the further that you go back in time the harder it becomes to tell what comes first. Then, when living creatures start engulfing one another, and swapping genes and maybe living inside each other, in a friendly fashion, it becomes even more difficult.

You've heard of Beatrix Potter, haven't you? "

"Squirrel Nutkin!"

"Peter Rabbit!"

"Renowned sheep-farmer" added the Prof, dryly "and you know what lichens look like" glancing meaningly at some greeny gray stuff on a nearby branch and some orange stuff on the tiles of the conservatory . "Smart lady, wrote books, drew nice pictures, bred sheep and even found time to recognise that lichens were made of two different organisms, fungi and algae, living together for mutual comfort and sustanance.


---Lady bird

"So what you're saying" said Billie "is that, way back at the very beginning , there could have been a lot of getting together, engulfing and living together"

"Must have been" said the Prof

"But what" asked Emily "do you think was the most important thing that happened. What made all the rest possible?"

"Well no one can deny that the arrival of DNA was immensley important. Wouldn't be much good today if someone came up with the sort of thing that everyone would like.....

"Like an iPod?" interrupted Billie, thinking of Christmas.

"...but didn't know how to make copies of it" continued the Prof, as though he didn't even want to think about Christmas yet. "but I think it was the invention of the wheel. The Archaeans came up with that very early on"

"You're talking about the Biddlestone Eye sort of wheel are'nt you?" asked Emily "and making electricity by letting water drive turbines?"

"That's right" said the Prof, " like I said' back in chapter five, present-day Archaeans make some of their ATP, like we do,by holding back protons behind membranes and then letting them escape through nanoturbines. That strangely enough, is where eyes come into the story".

"I wondered" sighed Billie "when you were going to get round to that. I bet it's one of your puns"

"Fraid so" said the Prof, "I suppose you could either call it a pun or an allusion"

"In parliament, if someone wins a vote, the Speaker says 'the ayes have it' groaned Emily "that's what you had in mind, wasn't it?"

"Fraid so" repeated the Prof, "I couldn't resist using it when I knew that I would have to mention eyes."

"Hang on " complained Billie "we're talking about three and a half *billion* years ago aren't we? Isn't that long before there were things with eyes?

"Quite so " said the Prof, "seems that cuttle fish, or the like, may have developed the first eyes about 500 *million* years ago. However our eyes contain a protein called rhodopsin that detects light. What's more it's chemically very similar to a purple protein called bacteriorhodopsin that has been around very much longer.

"For three and a half *billion* years?"

"If you'll excuse yet another pun, that's how it looks. continued the Prof, "More importantly, there are modern-day Archaeans that use bacteriorhodopsin to pump protons to the outside of a membrane and when they flow back....".

"They turn little turbines that make ATP" finished Emily, triumphantly.

"That's it" said the Prof, "all living organisms need energy. Seems like they not only learned to pump protons through membranes at a very early stage but also how to let them escape through a nanoturbine that could make ATP. As you know, most of the electricity that mankind uses for just about everything, is generated by turning a wire coil in a magnetic field and a lot of the turning is done by turbines driven by water running down hill. That water gets to the top of hills because the sun turns water into steam and that eventually condenses and falls as rain. A round about way of converting light energy into electrical energy and not too different in principle from what the ealiest Archaea did three billion years or more ago."

"So the Archaea did a sort of photosynthesis" said Billie " but not proper photosynthesisis. They used light to make ATP from ADP but they didn't give off oxygen"

"Or use carbon dixide to make stuff" added Emily, for good measure."

"It all depends" said the Prof, " what you mean by 'proper photosynthesis'."

"Proper photosynthesisis." protested Billie "Is what green leaves do isn't it? The Archaeans don't even have chlorophyll do they?"

"No" said the Prof, " they don't have chlorophyll and they don't evolve oxygen but, these days, what you call 'proper photosynthesis' is called *'oxygenic photosynthesis'* and there are other sorts that have been given all manner of fancy names".

"Try us with one, for starters" said Emily, just the merest shade impatiently"

"Well, since the Archaeans use light-energy to make ATP, this qualifies what they do as photosynthesis but, because they don't evolve oxygen, it's now described as *anoxygenic* photosynthesis and if you would like something really fancy how about a new lot of photosynthetic bacteria called aerobic anoxygenic photohetrotrophs?"

"Phew!" said Emily

" Only the cyanobacteria and the 'you-carry-oats' that contain chloroplasts, like algae and plants, do oxygenic photosynthesis".

"Proper photosynthesisis.?"

"Yes Billie, what you would like to call 'proper photosynthesis' and what Charles Reid Barnes had in mind when he invented the word. They split water, the oxygen comes off. The hydrogens are used to reduce CO_2.. All of the other photosynthetic bacteria do anoxygenic photosynthesis."

"Improper photosynthesisis.?" asked Billy, tongue in cheek.

"No Billie", said the Prof, patiently "photosynthesis that doesn't use water so it doesn't give off oxygen"

"At school" said Emily, "we've done an experiment where we shine a light on water weeds and count the bubbles that come off. How did you measure oxygen, when you were still working, Prof?

"You make it sound like ancient history" said the Prof, somewhat ruefully "but, come to think of it, I gave up working (for a living) before you were born and that must sound like ancient history to you two. Anyway, since you ask,, my favourite way of measuring leaf photosynthesis, back in those long past times, was with an oxygen electrode"

"Did you invent it?"

"Kind of you to think that I might have done" smiled the Prof, " I used an oxygen electrode of the sort invented by Leland C. Clark back in 1954. For more than half a century now, Clark-type electrodes have been mostly used for mesuring dissolved oxygen but they are also very good for measuring oxygen in the air. I had a very good friend called Tom Delieu who could make just about anything out of anything. So I asked him to make me a little transparent chamber out of plasic with room inside for a Clark-type electrode and a disc cut from a leaf. We called it a 'leaf disc electrode chamber.....'"

"That figures" grinned Billy,

.... it was intended for students in the first place but it sort of grew...

"Like Topsy?"

...... and it got used for all sorts of experiments, such as measuring quantum yield"

"Hang about" said Billy, somewhat sharply" What's that when it's at home?

[When this pagewas written Billie was eleven (going on sixteen) and, like all incipient teenagers, didn't always choose her words too delicately]

"Its a bit" said the Prof, "like miles per gallon but, since we are talking about leaves giving off oxygen, that becomes molecules..."

"per photon?" suggested Emily,

"Exactly so" said the Prof

"So how many oxygens can you get per photon?" asked Billy

" Here, in the border country," said the Prof, " there are lot's of sheep to the acre but in some dry parts of Australia it's more like acres to the sheep. It's a bit like that with photons and oxygen. At best, it's an one eighth of an oxygen per photon. Or you can turn it round and say that it takes eight photons to release one molecule of oxygen from a photosynthesising leaf.

"At best?" asked Emily.

"Yes, at best " said the Prof, " What we are talking about now is the *maximum* quantum yield.. Back in the 1950's there was a big argument going on between Otto Warburg, who thought it was four, and Robert Emerson who was convinced it was about about eight.. This was finally put to rest by Olle Bjorkman and Barbara Demmig using a......"

"..... 'leaf disc electrode'?" guessed Billy

" That's right" grinned the Prof.

"Bet that pleased you" .

" Certainly did"

" So they got one oxygen per eight photons?"

" For 37 different species they repeatedly got very close to nine".

"That's pretty near eight" conceded Billy, " but why not exactly 8 and why are you so sure that they got it right?".

" Well first of all" said the Prof " in science if someone comes with something interesting others try to repeat their experiments. I was very well placed to do that and got near enough the same sort of results. Then together with my friends at Hansatech we came up with an automated computerised version of the leaf disc electrode. That meant that I could measure quantum yield in as little as 10 minutes and I could repeat it again and again and again" .

" And why not exactly eight?. Leaves use oxygen to respire in the light as well as in the dark. They only use about a tenth of the oxygen that comes off in photosynthesis but any oxygen consumption would increase the apparent quantum requirement. so you would expect the measured number to be a bit more than eight and, in fact, it was always nearer nine than eight and never less than eight. .

"Why" asked Emily, "did it matter so much whether it was four or eight?"

" Had to do" said the Prof. "with trying to figure out how photosynthesis worked and you must remember that when this particular controversy was at its height there was much less known than there is now. What was known for sure was that, like everything else, it had to obey the laws of physics. The most compelling of these was the law of photochemical equivalence"..

"Oh dear, I'm beginning to wish I hadn't asked"

" Not so bad as you might think. All it means is that one....

.....photon hits a leaf causes one molecule, of whatever, to react.. We know how much energy a photon of photosynthetically active light contains and how much energy it would take to make CH_2O from CO_2. Turns out that one photon isn't nearly enough so there has to be several steps, one step at a time, each driven by one photon. Half a century or more ago, the biq question was how many steps".

" Otto Warburg was a Nobel Prize winner so, when he insisted that there were not more than four steps, ---".

"You would have to be quite brave to argue?" suggested Billy ,

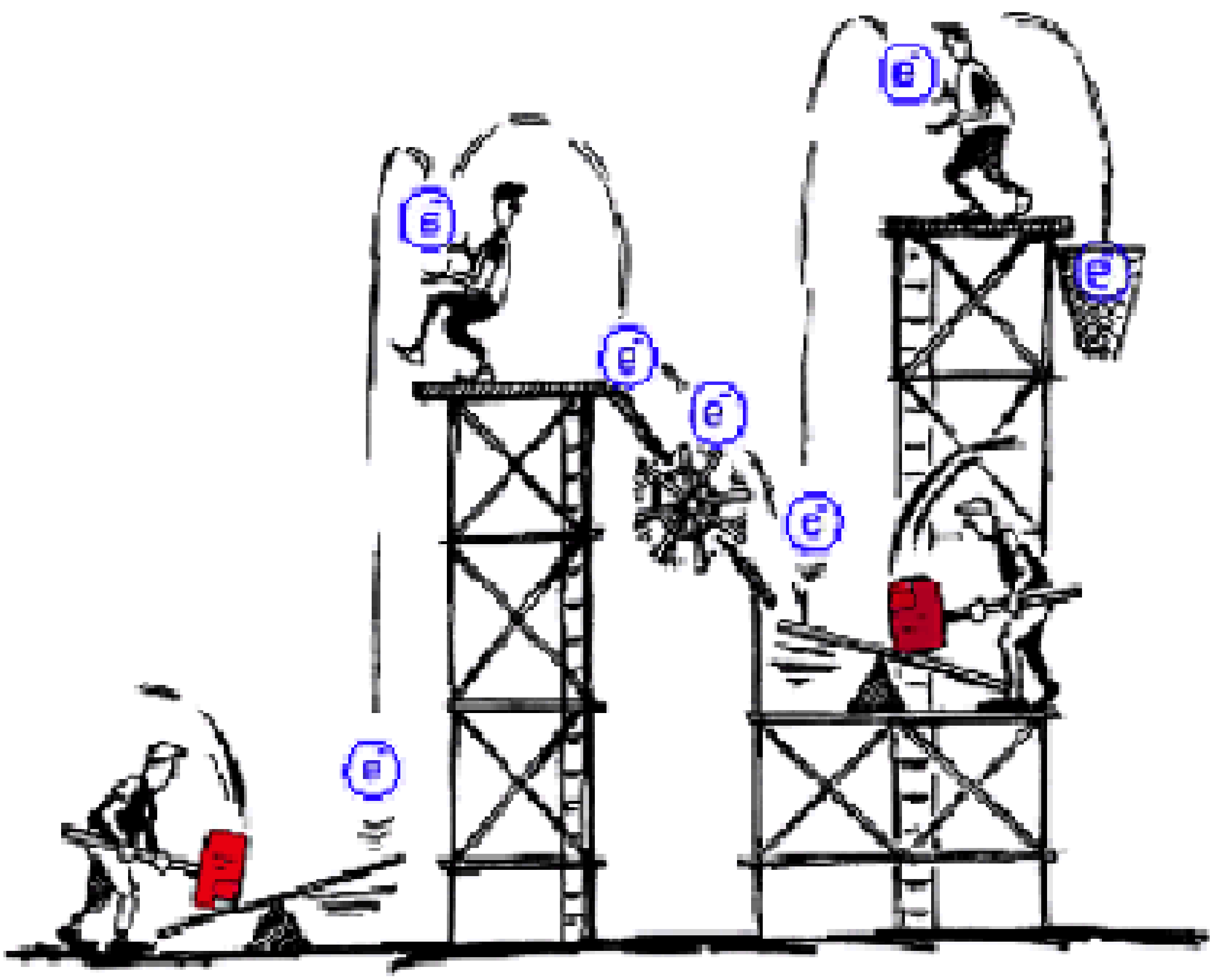
" Very brave" said the Prof. "but Robert Emerson was very brave and. about this time, he got a lot of support from a famous Nobel Prize winning physicist, name of James Franck, who could see that Emerson's results pointed to a much more plausible mechanism based on eight steps".

"So was that the end of the argument? asked Emily,

" Fraid not" said the Prof. "it rumbled on for a long time. Seemingly endless experiments to try and see where Warburg had got it wrong. but it was finally overtaken by Robert Hill's Z -Scheme which was supported by all manner of different observations as well theoretical considerations like those of James Franck..

"My Dad did a cartoon about the Z-scheme" said Billy, proudly"

" Certainly did" said Grand-dad, equally proudly "much sought after and now we've got an opportunity to show it again"



" As you can see, its based on two men with hammers and, each time that they strike a blow, a pretend electron (in blue) shoots up into the air and is caught by another man. The first of these puts his electon on to a downhill slope and as it runs down it turns a wheel"

"That has to be THE wheel, hasn't it?" said Emily, "Like the nanoturbine we talked about on page 38 that makes ATP from ADP.

" That's right" said the Prof. "what's more Richard first drew the cartoon back in 1979 long before anyone knew that there really was a wheel that made ATP from ADP"

"Case of science imitating art, you might say?"

" You might" said the Prof. "but remember that, although it's electrons running downhill that build up a head of protons behind a membrane dam, it's the PROTONS that turn the nanoturbine as they escape through it. And ,of course, each hammer blow represents an incoming PHOTON. Eight electrons have to accumulate in the basket (which represents $NADPH_2$) in order to release one oxygen. So, Richard's cartoon, like the Z-scheme that it illustrates, has a quantum requirement of eight

[Remember, dear reader, not to confuse protons (i.e hydrogen ions) within photons ('parcels'or quanta of light)

"Everybody's talking about energy these days" said Emily, endless stuff about calories but you don't here a lot about photons. How many calories are there to the photon?

The Prof looked a bit taken aback by this but, after a moment or two's thought, said. "About forty two if we are still talking about the Z-scheme. That's what one photon, of the sort of red light that's best for photosynthesis, is worth. But when "everybody" talks about 'calories' they usually mean kilocalories. Confusing I know, but it's traditional. And then there's the Avogadro number.

"That's a very big number* that you have to multiply by so that hydrogen weighs one gram and carbon weighs twelve and so on, isn't it"?

"That's right. If you want toknow how many calories there are in anything whatsoever it's best done in moles".

"No shortage of moles round here" said Billy, glancing across at the mound of soil on the grass.

"Even had them in my greenhouse" agreed the Prof "but right now we are talking about moles as in gram molecules"

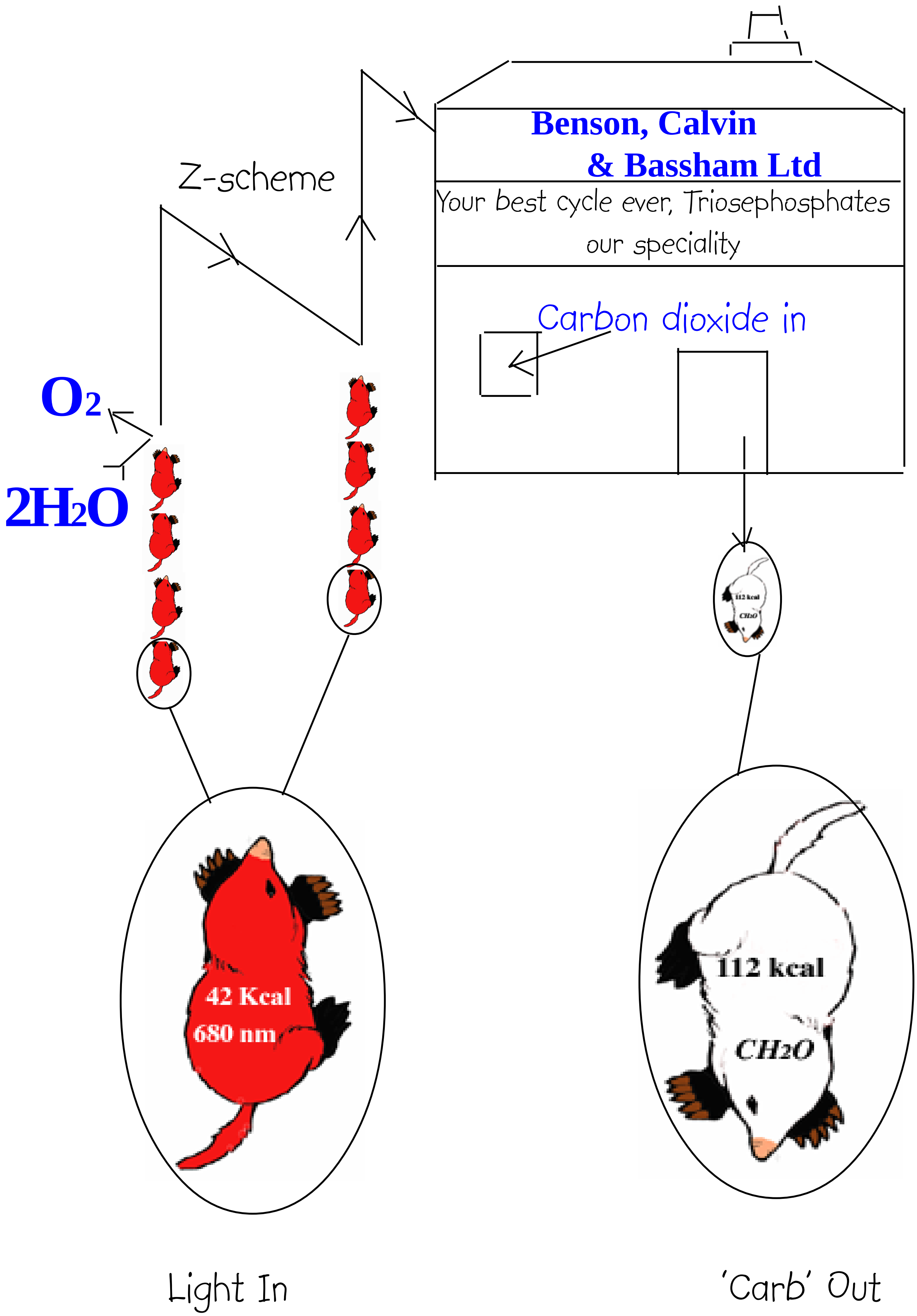
"And a mole contains the Avagadro number of molecules molecules"?

"Just so so" said the Prof "and no not only molecules. You can have a mole of ....

Photons?"

"That's my girl girl" smiled the Prof "so, to be precise, when I said " about forty two two", I meant that one mole of photons of red light with a wavelength of 680 nm would weigh in at 42 Kilocalories. What's more, if you burn one gram molecule of C6H12O6 in a calorime calorimeter you get out 672 Kcals of heat energy energy. That means to make such a "carb" you would have to put in at least 672 Kcals of llight energy That's 112 Kcals for every CO2 consumed. And, since the Z-scheme requires 8 photons, that means 8 x 42 = 336 Kcals used and 112kcals stored; and an efficiency of about 33%.

I've put all of this in a bit of picture, 'moles and all' on the next page and, if I got it right, the red mole should be reflecting 680nm light into your eyes"


Benson, Calvin
& Bassham Ltd
Your best cycle ever, Triosephosphates our speciality
Carbon dioxide in
Z-scheme
O_2
$2H_2O$
42 Kcal
680 nm
112 kcal
CH_2O
Light In
'Carb' Out

"However," said the Prof "there are more ways of skinning a cat...

"Ugh" yelled Billie

"There are other ways" said the Prof, correcting himself, "of looking at it. If we are back to Calories with a big 'C' and how much we eat and how fat we have become and all that , better perhaps to think about cricket".

"What" complained Emily, "Has cricket to do with it"
"Not a lot" agreed the Prof, "apart from the fact that we English invented it (along with rugby and football) and that a cricket wicket is 22 yards long"

"Rings a bell" conceded Emily, "an acre is 22 yards wide by 220 yards long isn't it?"

"Such" said the Prof, "are the vagiaries of English history and, to come to the point, we can therefore reasonably ask what percentage of the light energy, that falls on an acre of land, can plants put into sugar, or whatever"

Turns out that sugar cane is the most efficient, in this regard, at about 1% and most food crops convert much smaller percentages of light energy into chemical energy of the sort that we can live on"

"Sugar cane" said Billie, " is not what you might call a balanced diet"

"True but, despite everything that you may have been told to the contrary, potatoes can provide you with all you need in the way of proteins as well as carbs and vitamins. This was proved by a man who lived for a whole year on nothing but potatoes. Seven pounds a day is more than enough and that works out at a mere 12 tons a year.. It's easy to grow that many even though spuds are not as efficient as sugar cane"

"Didn't all those carbs make him fat?" asked Emily.

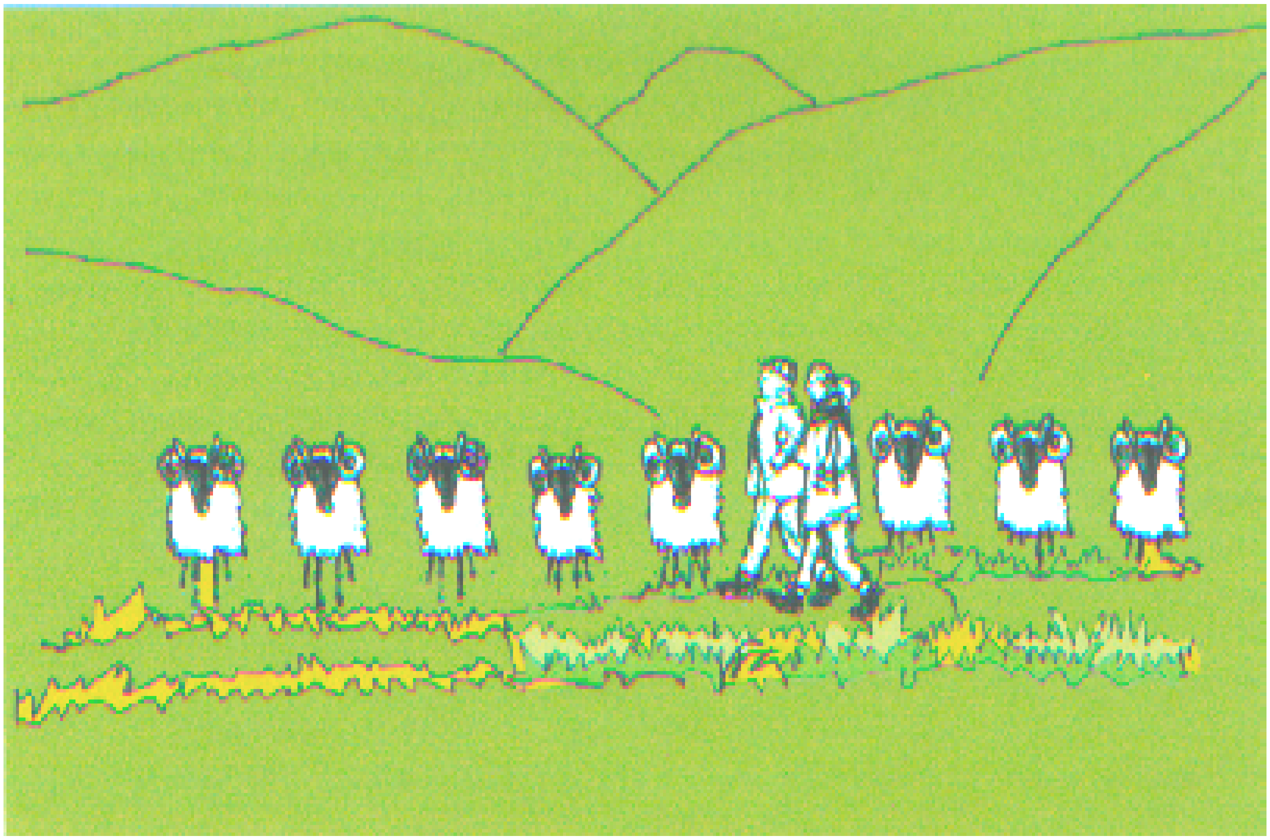
"It's the number of Calories that count, not what they come packed in. Besides potatoes have all the protein that you need anyway...What's more you can easily grow twelve tons of potatoes on one acre of land and that means that one acre can provide enough food for twelve people for one year. If you do the same sort of arithmetic for corn, or whatever, you come up with approximately the same values.

"When you go for a gentle walk, for half an hour or so every day, with Grandma how many Calories does that use?"

"I weigh about 160 pounds on a good day so it works out at about one hundred Calories with a big C"

"Wouldn't you use a lot more if you walked a lot faster?"

"Only if you walked a lot faster for the same length of time because that would mean going much further. The difference between walking a mile at 2 miles an hour and running a mile at ten miles an hour is only about 15%. All to do with Newton's Laws of Motion and such."



This is a drawing (by Marney)walking with her mother (Curly Shirley) in Upper Coquetdale. Marney is a vegetarian but her mother is partial to a leg of lamb with mint sauce. Right now she will be glad to get safely past big sheep with big horns

"So you go for a gentle walk, for half an hour or so every day, with Grandma and that means you burn off about 200 Calories between you?"

"That's right"

"When you share a bottle of wine with Grandma every evening at 6 oclock, how many Calories does that put back?" continued Billie, with a grin.

"You are" smiled the Prof, thinking of Kipling and the 'Just So Stories', "a girl of considerable perspicacity. Well, to be fair to Grandma, she only has one glass and I drink the rest but, to answer your question, one litre bottle of good German dry wine, like the sort that Carina sends us from Buergerspital, contains about 550 ."

"Talking about wine and Calories and stuff " said Emily "Tell us about bioethanol"

"Controversial subject" said the Prof "President Bush thinks that if you take corn or any other plant material that you can ferment and distill, so that you finish up with alcohol that you can put into car engines you won't need to import so much oil"

"Sounds O.K "

"Up to a point. But, as we all know there are no free lunches. There are those, like David Pimentell, who say that you have to put more energy, in the way of oil or whatever, into making bioethanol than you get out in the ethanol that you produce."

"Is he right?"

"I'm sure he is" said the Prof "In a book I once wrote, called "Energy, Plants & Man', I said that Western Agriculture was a very expensive way of turning oil into potatoes"

"Meaning?"

"That if you add together all the energy from fossil fuels that is used, such as fertilisers, herbicides, machines, transport, refrigeration, storage ,distribution etc you finish up with a lot less energy in the food, such as a potato or whatever, that finds its way on to your table"

"But doesn't making bioethanol from things like corn gain more energy than growing it for food?"

"Depends on what you use and where you stop counting. If you grow corn for food you don't use all of the plant but if you grow it for biomass you can use a lot more. On the other hand, while it's easy to make dilute alcohol you have to distill it if you want to use it as a fuel. Just as turning water into steam takes a lot. of energy so does distilling alcohol.

" What did you mean by "where you stop counting'?"

"Think about Sheffield" said the Prof " England's fourth largest city with a population of just over half a million but the population of "urban Sheffield" is more than twice that and if, you were driving through it, you would be hard put to know where the city stopped, even though it is supposed to be one of the easiest cities to get out of.

However hard you try, it's also hard to know where to stop counting if you try to figure out the energy costs of making bioethanol. Better, perhaps. to trust what David Pimentel has to say than politicians or the National Corn Growers Association."

"Seems to work in Brazil, doesn't it ?"

"Up to a point" said the Prof, thinking of an occasion in Fortaleza when a taxi and its driver, both fueled by ethanol, drove through a red light. "They make very good use of the bagasse, that's left after they've extracted the sugar. Brazil is a very big country and they use very much more manual labour, in agriculture, than in Europe and the United States."

"So it can be argued that they get back about 25% more energy than they put in. Back in North America this sort of return is most unlikely and of course the maize and wheat that is grown there feeds much of the world. Half a century ago there was much less grown but the yields per acre have grown steadily because of more eficient agriculture and, in particular, the advent of selective weed killers. Similarly the world population has grown in step with grain production. Whether or not this has happened because farmers have grown more, it still means that more land for bioethanol means less land for food. Already the price of corn has risen. It is sometimes claimed (I think wrongly) that agriculture can easily feed the worlds growing population and that so many starve only because they are too poor to buy what is grown. In the end it doesn't really make much difference if you go hungry because there is no food to buy or you are too poor to buy it "

"You said that one acre can grow enough food for tweve people for one year didn't you?"

"Approximately "

"If you used that acre to grow corn to make into bioethanol how many cars would it keep running for one year?

"Not even one, Obviously it depends on size of the vehicle and the average number of miles travelled in a year. Here in the U.K we tend to have smaller cars and drive less miles than in the United States but it would still take more than one acre to keep the average 'automobile' running the average mileage for one year."

"So one car eats as least as much as twelve people?"

" Yes. Good way of putting it. And, if Pimentel, Paztek and Cecil are right, as I believe they are, and you wanted to make bioethanol without using any energy from gas or oil you would have to use much of what you made to drive the farm machinery, the distillation process, taking the corn to the still and the bioethanol to where it was needed. That's why the price of corn and wheat have gone up recently and why there is real concern that the more land is used to feed cars the less there will be to feed people"

"But" protested Emily, "I've read that we can grow more than enough food to feed everyone and that's why there are these funny looking fields called set-aside"

" Set-aside used to be called 'fallow' in my day" sighed the Prof "True enough that most people in rich countries don't go hungry but not much comfort to many people in Africa who are starving right now. For fifty years or more, world food reserves were about 40% of annual consumption but since 1999 they have shrunk by half. Right now, in 2007, Australia is having the worst drought in 100 years. North America is not immune to droughts. Remember "The Grapes of Wrath'. If there happened to be a long dry period in the 'corn belt', when more and more land had been given over to bioethanol production, the margin between global food reserves and global food consumption could become perilously low."

"Grand-dad" mused Billie, You have a beard and so did Doc in Cannery Row."

" Mere coincidence" said the Prof, much flattered and embarrassed by the implied resemblance. " Time we got back to the beginning of this story."

" This book, if you can call it that" said the Prof, . "was intended to be about how green creatures have changed the world"

"But you've lost the plot" said Emily.

"And not for the first time " agreed Billie.

" You are quite right" said Grand-dad, "I've left an awful lot out and there is absolutely no way that I'm going to get it finished before the Photosynthesis Congress in Glasgow this July.
I'm reminded of a quote that goes like this"

"It's been a tedious journey
and tiresome it is true
but see how many dangers.......

"...the Prof has brought us through" finished Billie, kindly.

"You could always add stuff afterwards by download " said Emily.
" Good thinking" said Grand-dad.

" Hang on" said the Prof, " If we are to stop here, at least for the time being, let's at least remember that it was many millions of years of photosynthesis that stashed away carbon dioxide in what became fossil fuels. Right now we are hell bent on putting it back into the atmosphere as fast as we can. So we are starting to run out of oil and natural gas and changing our environment in a big way.. As Dennis Healey said, better if you are in a hole, to stop digging. Better, in this context to go for much more energy conservation. Also much to be said in favour of photovoltaics which are ten times more efficient than crops at turning light energy into electrical energy "

Yet another unfinished story

As I write this on 07/0707, which happens to be the fifty second anniversary of our wedding, 'A New Leaf in Time' is not finished. Despite Shirley's unfailing support, there was never any likelihood that it would be. On the contrary it is remarkable that it has progressed as far as it has. Herein lies yet another virtue of a book in digital format. Had it been intended for publication on paper, like the score of a piece of music that was destined never to be played, that would have been the end of it. As it is, unlike an old book gathering dust on a shelf, it can still be added to or corrected. Therefore, patient reader, if you find something in it that you feel should not go unchallenged please do not hesitate to tell me and, while opportunity permits, I will do what I can to put it to rights.

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