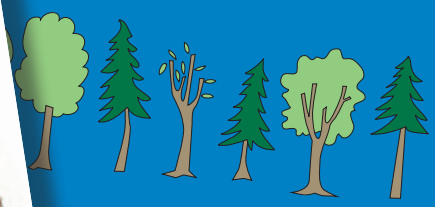
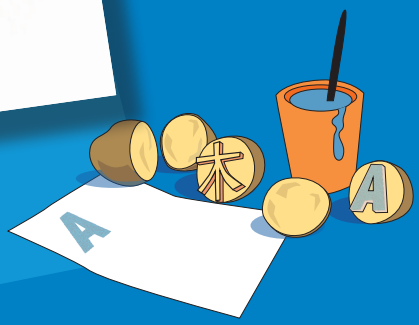
The story of paper

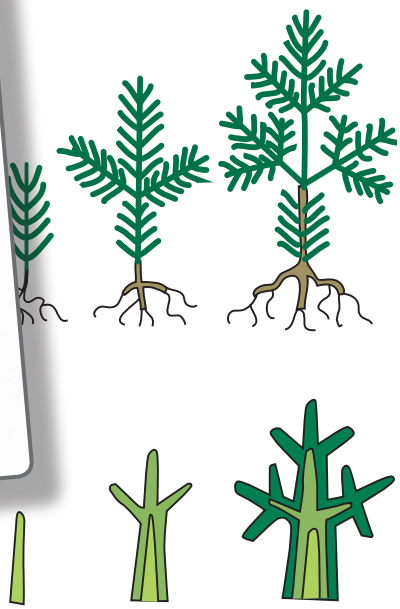
trees and printing





Malene Bendix
Artwork by Eva Wulff

The story of paper trees and printing



Malene Bendix

Graphic Association of Denmark
and Forests in School in Denmark.

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You can find additional teaching materials in Danish - at www.skoven-i-skolen.dk.
Use the search word “papir”.

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The book is free of charge

Table of content

Grandpa's trees

“ Hi Grandpa, what’s up?”
“ Oh hi William. What are you up to?”
“ I think you are sleeping”
“ Me sleeping? Nah! I’m just thinking and enjoying the silence-
with my eyes closed!”
“Oh. What are you thinking about?”
“I am thinking about my forest. I should harvest some trees, and
then I came to think that they could become paper”
“Paper, but can you make that from trees?”
“Yes of course. Paper is tree, or it is made from trees.
Would you like to see?”
“Now?”
“Yes, come with me.”

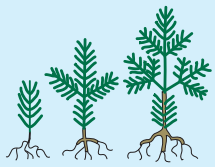
Paper and the trees from the forest

"Have a look at these trees, what do they do?"
"They are growing."
"Yep, they are growing. For each year passing, they become taller and thicker. We have planted them quite close to each other, so that they can provide shelter for each other. But at some point they have grown so large that they need some more space and light. So I did some thinning. That means I harvested some of the trees, to provide more room for the ones leftover."
"So what do you do with the trees you harvest?"
"Good question. They are too small to become boards or furniture. What do you think they can be used for?"
"Paper?"
"Yep."
"But, aren't they full of branches and bark?"
"Yes, but the trees are chopped into tiny pieces that are cooked into a kind of porridge called paper pulp."
"Pulp – that is a strange word."
"Pulp means mass, paper mass."
"How do you make paper from this pulp?"
"I will show you, come with me to the kitchen."

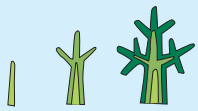
Which trees become paper?

Did you know that you can make paper from both conifers like spruce and pine - and hardwood such as birch, beech and aspen?

How does a tree grow?

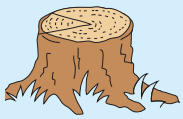


Did you know that a tree grows in two ways?
It grows taller – and it grows thicker.



Taller: The tree grows at the tip of the branches and roots, by forming new buds that grow out.

Thicker: The tree also grow thicker, just inside the bark: Every year it creates a new annual ring of wood all the way around the trunk and the branches.



Try to look at a stump or a felled trunk. Count the annual rings, and find out how old the tree was.

On conifers you can also count the whorl of branches created each year. Add 4 to the number and you know the age of the tree.

- How many years does a tree need to grow one meter, two meters?
- How much has the tree grown each year?
- How come they don't grow the same length each year?

Which trees can be cut when thinning the forest?

Did you know that foresters do thinning in young forests? They cut sick or weak trees to give room and light to the trees leftover to grow big and tall. Here you can see which trees that will be taken out.

Healthy tree
Long, straight trunk. This makes straight boards and planks.

Whip
Long, thin trunk with a small crown. This would whip and damage the other trees.

Bifurcation
The tree has split into a double trunk, making the trunk too short to cut boards.

Jar
A tree with large amount of branches, that takes up too much room.

Crooked tree
The tree has grown crocked. It cannot provide straight boards.

Sick tree
The tree has a disease, or it is injured. It won't last long.

Paper and fibre

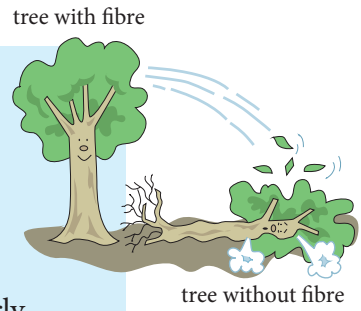
Recipe for paper pulp

This makes paper pulp for approximately 25 sheets of paper.

- ½ kg old paper
- Water
- Bucket or bowl
- Blender, or electric whisk

"What's up, grandpa?"
"You know, the trees are so strong and flexible that they can resist a storm. If you could look into a tree, you would see that the wood consists of long, thin cells. Some of the cells stiffen the wood so that the tree won't fall over during a storm. These are called fibres. They are the ones we use when we make paper."
"How do we get the fibres out of the tree?"
"We don't, because we can't do that here by the kitchen table. But we can get hold of the fibres in another way. There are plenty of them around us."
"Where?"
"In paper; newspapers, envelopes, books and magazines. The wooden fibres can be used several times, six times in fact. So we make our paper pulp from old paper."
"So it becomes recycled paper?"
"Yep. Fetch me a bucket and I will show you."

Look, we take mostly white paper, and some newspaper, otherwise the paper would become grey in colour. Then we tear it."
"How big should the pieces be?"
"Small. The smaller, the better."
"Nice work."
"Then we add boiling water. It should just cover the paper. Then we leave it for some hours, preferably overnight."
"Then what do we do?"
"I'll show you. Let's go to my workshop."

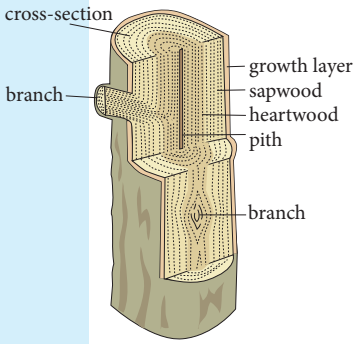


About wood fibre

Did you know that wood fibres are long, thin cells with thick walls, which run along the inside of a log? The fibres brace the tree and make it strong and resilient.

Wood fibres are tiny. You need a microscope to see them clearly.

- Fibres from conifer trees are between 2 and 6 mm long. The length of the fibres gives the paper strength.
- Fibres from hardwood are between 0.5 and 1.8 mm long. The short fibres add volume to the paper, and provide a smooth surface.



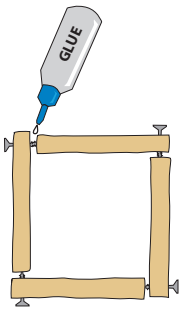
If you look inside a tree trunk, you would not be able to see the fibres with the naked eye. But there are wood fibres in all the wood inside the bark. They run vertically up the tree.

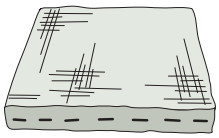
The thick wall of the cells makes the wood very strong. Chemically the walls consist of a substance called cellulose. That's why wood fibres are also called cellulose fibres. A quarter of the wood you see in a log is cellulose. The fibres are bonded together by a substance called lignin.

Find fibres

Decomposing wood is a tough job, but mushrooms are really good at it. Find an old, tender branch from the forest floor. If you break the branch with your fingers, you can see all the fine fibres. Try to smell the branch. It will smell of mushrooms because of the fungi eating the wood fibres.

Paper and frames





"So William, can you use a saw?"
"Yes, it can't be that hard. "
"Good, because now we are going to make a paper frame."
"Ok, you let me know what I shall saw."
"We want to make two identical frames. Just like picture frames. One with a mesh and one without. Can you make four lists of 18 cm each and four lists of 24 cm?"
"Yep."
"And then we make two frames by screwing the pieces together, and we attach the mesh on one of them."

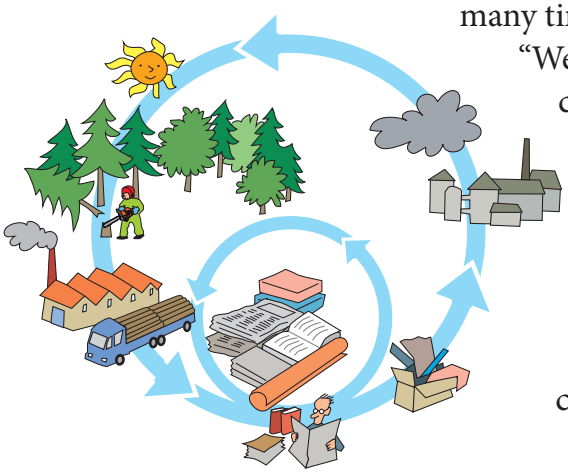
What you need to make a paper frame:

- Wooden lists 3x3 cm (see instructions for the length)
- Ruler
- Saw
- Wood glue
- Stainless steel screws
- Screwdriver
- Electric drill (optionally)
- A stapler, and stainless steel staples
- A mesh of nylon or steel, with a mesh opening of 24 pr. cm^2

Size of the paper	The number of lists you need	The size of the net you need	Cut the lists this length
21 x 29 cm	2 each of 1,12 m	37 x 45 cm	4 each of 24 cm 4 each of32 cm
15 x 21 cm	2 each of 84 cm	31 x 37 cm	4 each of 18 cm 4 each of 24 cm
30 x 30 cm	2 each of 1,4 m	46 x 46 cm	8 each of 35 cm

Paper, climate and photosynthesis

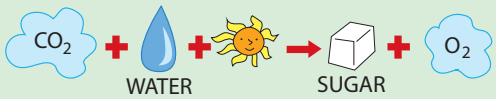
"There's something I've been thinking about grandfather. Did you know that trees captures CO_2 from the air with their leaves, and build it into their branches and trunk? And in that way, the trees store the CO_2."
"Yes."
"So if the paper is wood, would paper then store CO_2 as well?"
"Yes, here is carbon from CO_2 stored in the paper"
"And when we burn wood - or paper, the smoke contains the CO_2 that was previously captured from the air, releasing it back into the air."
"Yes."
"Would it not be better for the climate then, if we used wood and paper as many times as possible?"

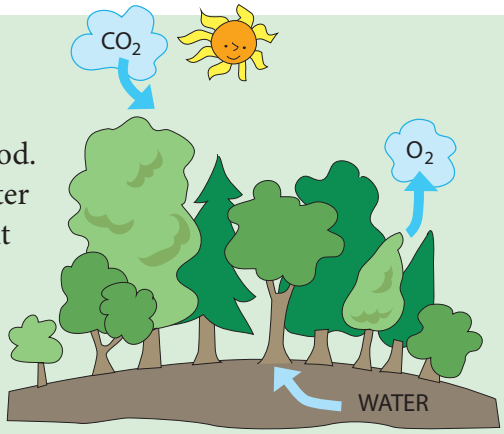


"Well, yes it is. And that is also the reason we collect paper for recycling. However, when it can no longer be recycled, we will eventually burn it. But paper will provide environmentally friendly heat, because it is made from wood, and not oil or coal. It will also turn into CO_2 and water, which can be obtained by new trees, and so the circle is completed."

Photosynthesis

Imagine a tree. It is growing, but it eats nothing. Trees and all other plants can make their own food. They use solar energy, CO_2 from the air, and water from the soil. This is called photosynthesis, and it can be illustrated like this:





When there is light, the green leaves capture CO_2 from the air. Inside the leaves the CO_2 is bound together with water and becomes sugar. The tree uses this sugar to make wood, branches, leaves, fruits and roots.

Photosynthesis is the basis for life on earth - and it's good for the climate as well because the CO_2 is stored in trees and plants.

Recycled paper

Recycled paper is made from old paper.

The ink is removed and the paper pulp is transformed to new paper. Some are made into cardboard while others become printing paper, napkins and toilet paper.

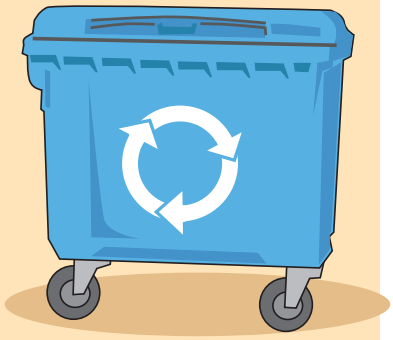
When making recycled paper, only half the amount of energy is needed compared to making new paper and less water is needed. So it pays off to recycle paper.

Recycle your paper

Did you know that some countries recycle paper, while others don't?

Find out what is being done in your country. If you do recycle, describe the routines and how you can deliver paper for recycling. If not, why?

What can you do yourself to recycle paper – or to make your society recycle?



The history of paper

"But how did people think of making paper, grandpa?"
"Hmm, that happened over a long period of time and it went through several phases."

Antiquity

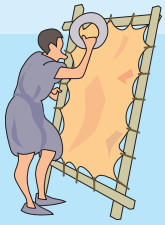
3000 B.C.

1. "The first people to make something similar to paper were the Egyptians. 5000 years ago they made a kind of paper that they called papyrus. Egyptians used the papyrus plant which grows along the banks of the Nile. They cut the stalks into strips and beat them into flat pieces, which then were pressed together into a crisscross pattern to form large sheets. And voila, suddenly they had something light and portable to draw and write on; paper rolls."
"How can we know this?"
"It is easy enough. Lots of scrolls made from papyrus have been discovered from archaeological sites in ancient tombs and cities in Egypt."

2000 B.C.

2. "What did people write on in other parts of the world at that time?
"In ancient times people made drawings on stones and rocks. And they carved characters onto boards made from stone, wood, clay, wax or they wrote on animal skin."

1000 B.C.



3. "2200 years ago, people from the city of Pergamon in Turkey discovered a way to create a kind of paper from animal skin. It was called parchment. The skins were made from sheep, goats or calves. The skin was soaked in lime water to dissolve the fat. Then the fur, fat and meat were scraped off. It was then stretched out on a frame to dry. Lastly, the skin was polished with chalk and pumice, to make the parchment smooth and thin. "

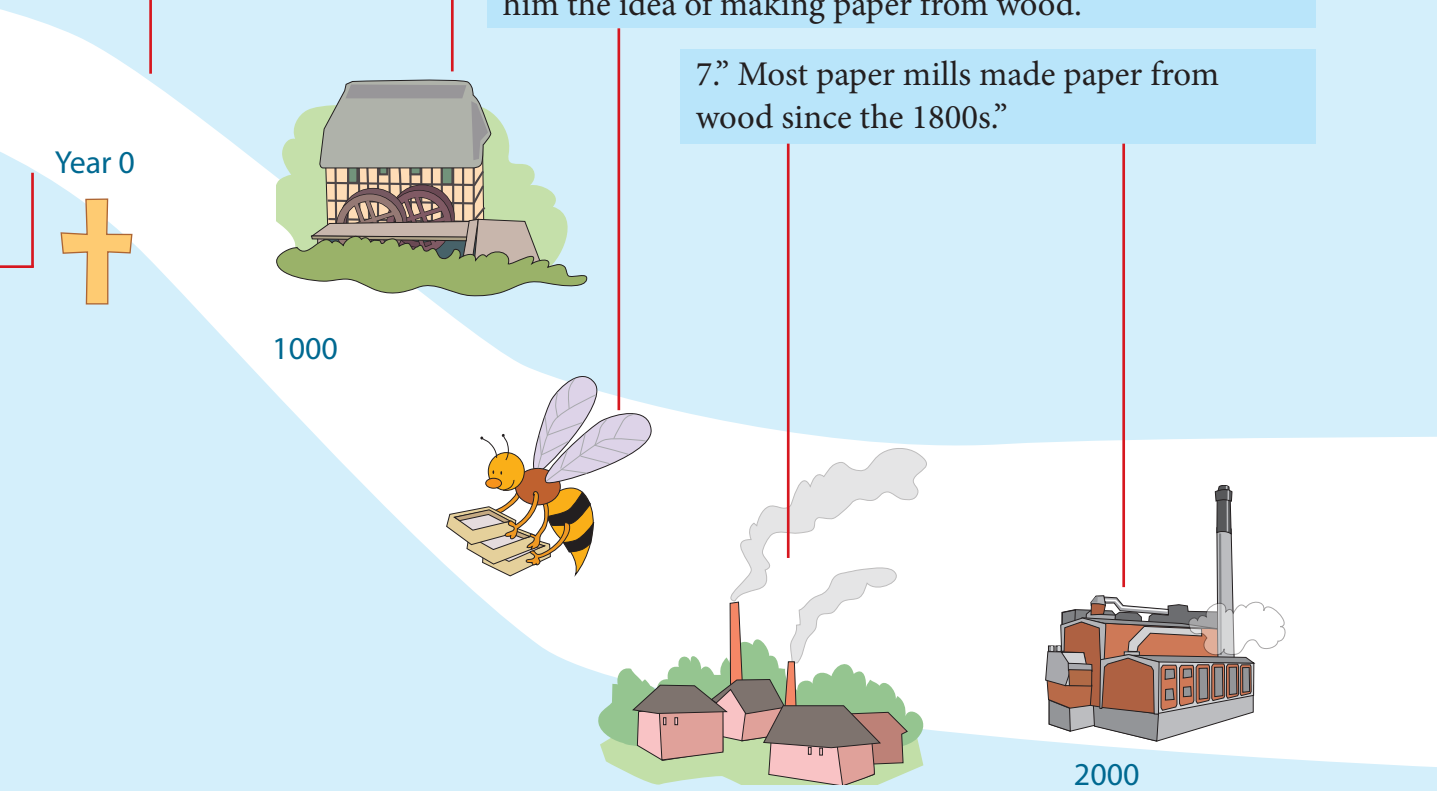
“Parchment was used extensively in the Middle Ages. It was cut into sheets, just like our paper today, and attached as books.
In the monasteries, the monks wrote books one by one. At that time books were a highly valued asset. That was before the year 1440, when Johann Gutenberg invented the printing press in Europe. Parchment was replaced by paper, which was invented in China about 2000 years ago.”

4. “In the year 105 a Chinese man named T’sai Lun, got the idea that it was possible to make paper from plants like cotton and linen. He crushed the plants in a stone mortar with a pestle; added water and stirred the mix. Then he dipped a large framed mesh down into the mass and pulled it back up again. A thin layer of crushed plants remained on the net. The water ran off the mesh, and when the plant mass dried, it stuck together like a sheet of paper.

5. “T’sai Lun’s paper idea spread from China to the whole world. It took a while for the idea to spread. The first paper mill ever built in Europe was in the 12th century.
At that time the paper was made from cotton and linen. “

6. “Not until the 1800s did a German priest study wasps in nature. He saw how they chewed wood mixed with saliva and used the mixture to build their nest. This gave him the idea of making paper from wood. “

7.” Most paper mills made paper from wood since the 1800s.”



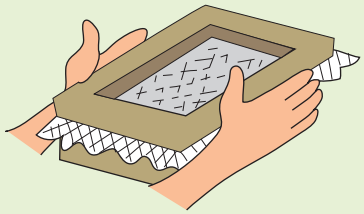
Making recycled paper

"Wake up grandpa, let's go and make paper."
"Slow down, William, I'm an old man. Make some coffee, and I'll be right along."

"The paper has dissolved!"
"Yes, now the fibres are released. Try using the electric whisk and whip the pulp."
"It's turning into a thick porridge."
"Then we have to add more water. It should be thin as slurry. The thinner the pulp is, the thinner the paper we can make. Look, the pulp is ready. Will you fetch me the frames, William?"

"The paper we are making here is called handmade paper. The surface hasn't been treated; we say that it is open. This gives a rough surface, but is nice to draw and write on. The white paper you use at school is called surface sized paper, which means that the surface has been sealed with glue. "

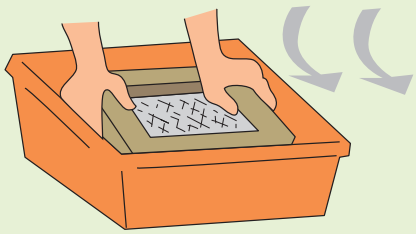
This is how you make paper



Take two wooden frames, one with mesh and one without. Hold them towards each other, so that the mesh is in the middle. Lay them flat and make sure the frame with the mesh is the bottom one.

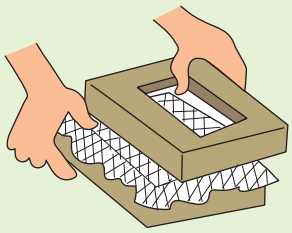
What you need for making paper

- Large bowl (larger than the frames)
- 2 frames - one with mesh
- Sponge
- Dry towels
- If possible, an iron
  - to dry paper quickly
- Paper pulp

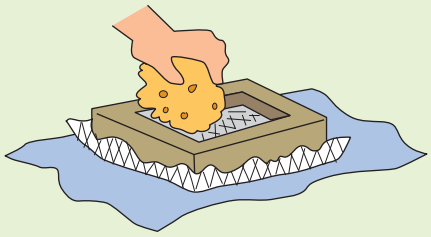


Dip the framework into the paper pulp until a thin and even layer covers the mesh.

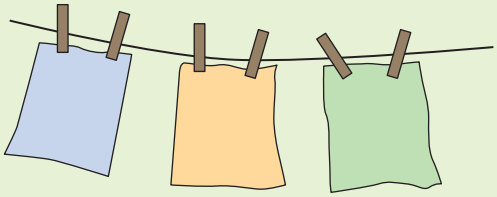
Take the framework out of the water, keeping it in a horizontal position. Let the water runoff.

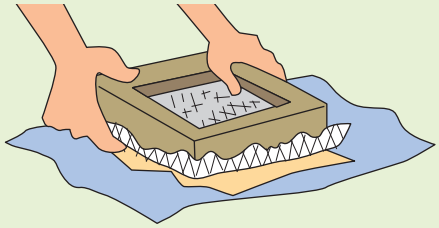


Carefully remove the top part of the framework.



Flip the frame with the wet paper onto a damp cloth. Sponge the back of the mesh with a sponge.

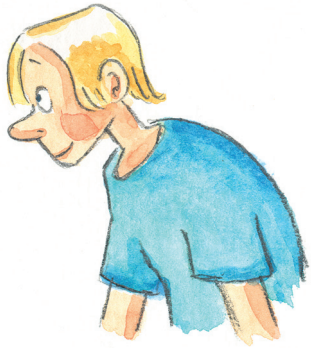


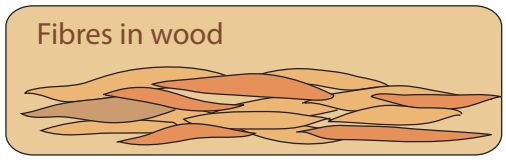


Gently remove the frame with the mesh. To dry your paper, either hang it on a string, or leave it inside a newspaper with some weight on top.

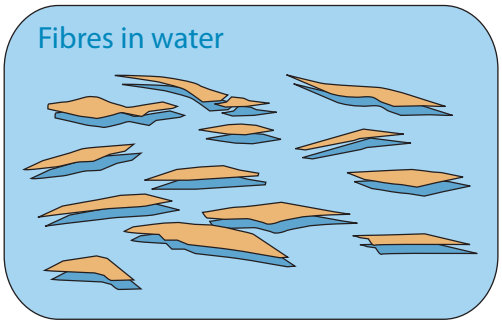
Paper and paper pulp

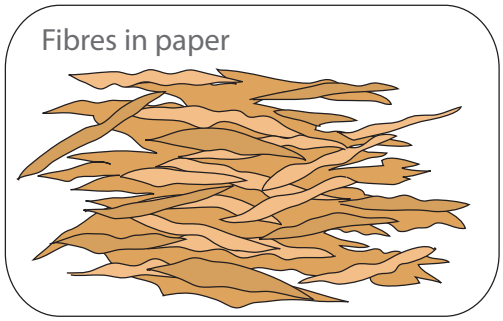
"Well, William, what did you learn about paper?"
"I learned that paper is made from wood. That the wood from the forest is chopped into small pieces and that in some way it becomes paper. But I still don't understand how exactly the tree becomes paper."
"Ok, listen: Inside the timber are fibres; they are packed closely together alongside one another.





You can see them with a microscope.
Those are the fibres that we use to make paper, just like our recycled paper. We separate the fibres and dissolve them in water. And then we collect them with the mesh which lets the water runoff."



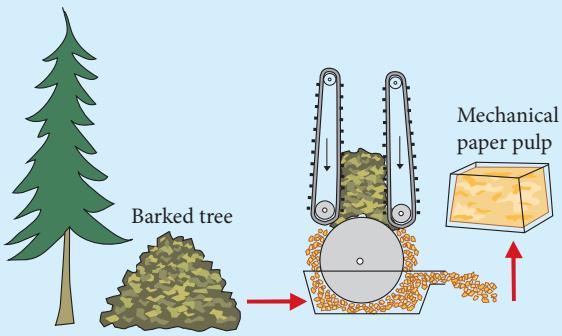


"But there is a problem. Inside the timber, the fibres are glued together with a substance called lignin. In order to use the fibres, they must be separated. Lignin is both good and bad. Over time it will make the paper yellow and fragile. But it also makes the paper good for printing.

Therefore, they make different kinds of paper pulp, depending on what you want to use the paper for. Here are the two most important ones: "

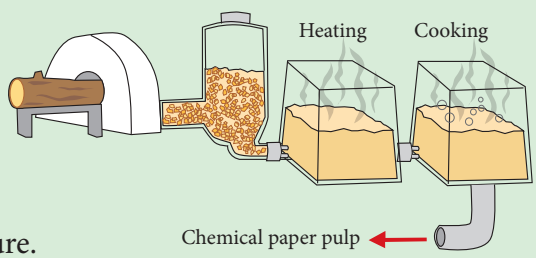
Mechanical pulping

The tree trunks are cut to lengths of 1-2 meters, and the bark is removed. The wood is then grinded into fine sawdust, so that the fibres are torn apart. The sawdust is purified and pressed into a sort of wet cardboard, which is then sent to the paper mill.



The lignin is not removed when paper pulp is made mechanically. Therefore, the quality is rough and the paper is used for newspapers, phone books and cheap books. In mechanical pulp, the fibres keep some of their wood-structure - and that's why this sort of paper is called wood containing paper.

Chemical pulping



The tree trunks are cut to lengths of 1 - 2 meters. The bark is removed and the wood is chopped into small pieces called wood chips. The chips are cooked in water with various chemicals. This process takes place under high pressure and high temperature. The lignin that binds the fibres together will dissolve and the fibres are separated. Then the pulp is cleaned, washed, bleached and dried into a kind of cardboard, which is sent to the paper mill.

Chemical paper pulp provides high quality paper. Some is bleached and become writing paper, books, envelopes, magazines, etc. Unbleached paper is used for wallpaper and wrapping paper. In chemical pulp the fibres lose their wood-structure. The paper is called wood-free paper, although it is made of wood.

"Do you understand now?"
"No - not quite. How does paper pulp become paper?"
"Ok, I will explain to you – have a look at the next page."

Paper mill

“This is a paper mill. The paper machine is 100 meters long, yet it does almost the same process as we did with our recycled paper.

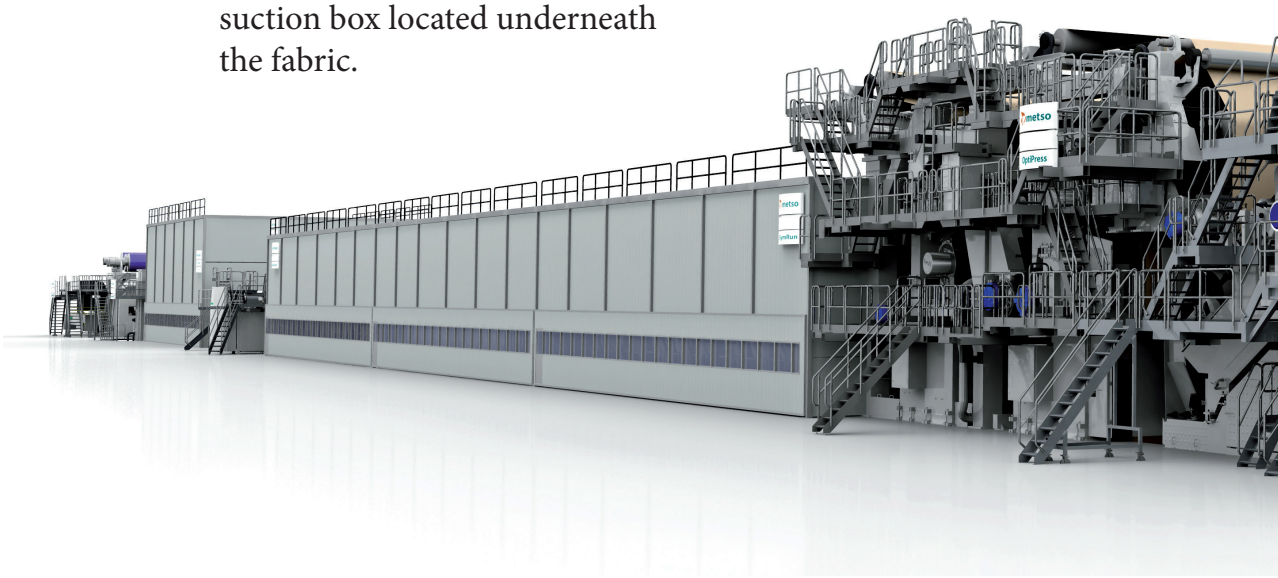
Before the pulp is ready for the paper machine, it is taken into a giant mixing bowl called the headbox. The pulp is dissolved in water and the fibres are beaten together. The paper pulp can be either chemical, mechanical or recycled pulp, or a mixture. Different substances are added to the pulp:

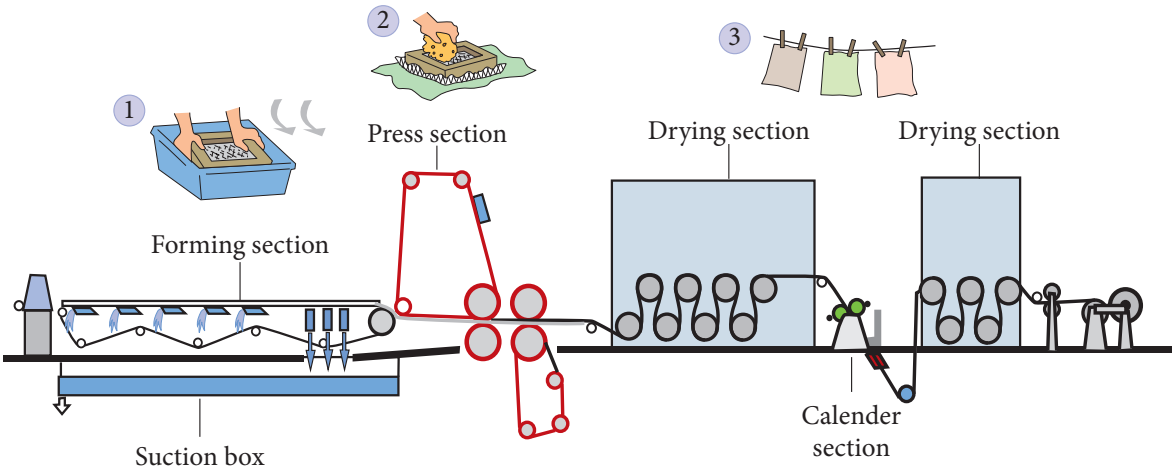
- Chalk – this makes the paper white, soft and smooth
- Clay – this makes the paper less transparent
- Starch – e.g. potato flour provides strong and durable paper

The paper pulp is now ready. Next, plenty of water is added to make it a thin slurry. 100 litres of paper slurry contain only ½ litre of paper pulp - the rest is water.

The paper machine consists of four sections: forming section, press section, drying section and calender section.

1. The forming section is a fabric loop which runs continuously between two rolls that are several meters apart. The paper slurry is poured onto the fabric, which with a little shaking spreads the slurry evenly. The fabric rolls forward with a long, wet web of fibres. It runs at high speed, often as much as 90 km/h.
A vacuum draws the water from the web into a suction box located underneath the fabric.

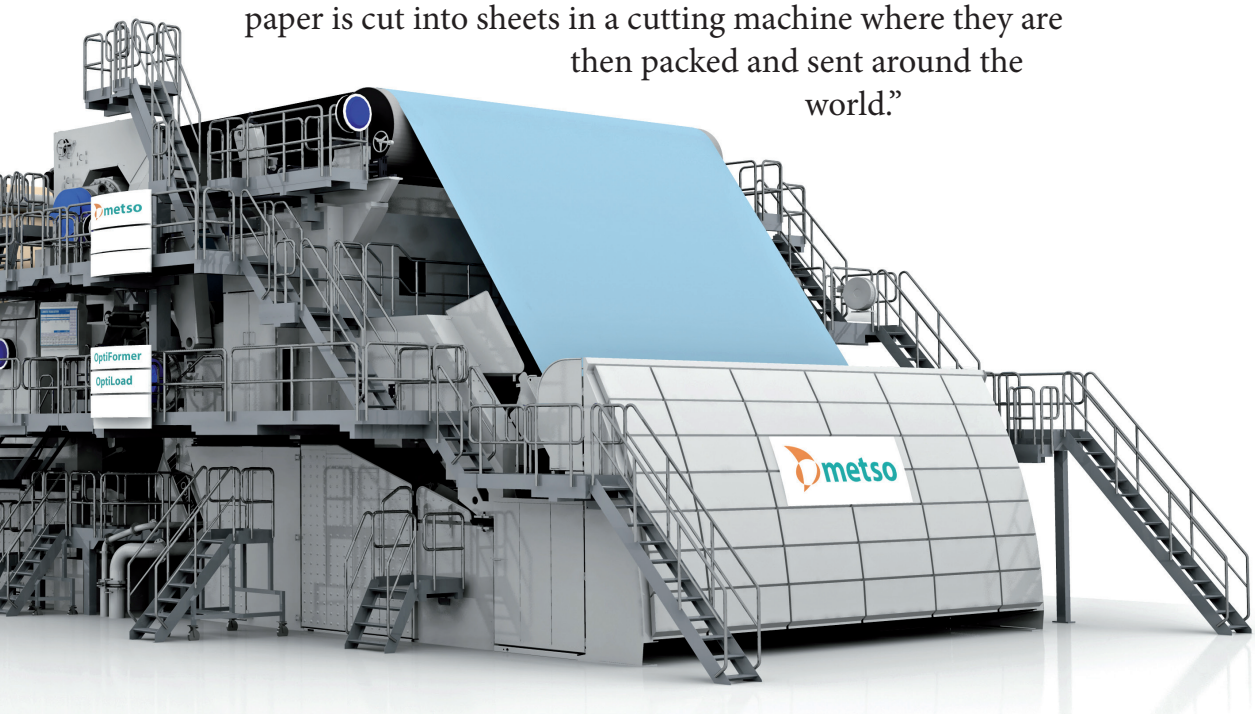




2. At the end of the forming section, the row of paper is pulled onto a conveyor belt that sends the paper through lots of rolls which press more water out of the paper. This is the pressing section.

3. In the drying section, the paper passes through cylinders that are heated. This makes the moisture evaporate, drying the paper completely.

At last, the paper reaches the calender section. The calenders are rolls that are used to make the paper surface extra smooth and glossy.
The finished paper is rolled up into a huge roll. Such rolls can be 8 meters wide and 30 km long and weigh 15 000 kg. Later the paper is cut into sheets in a cutting machine where they are then packed and sent around the world."



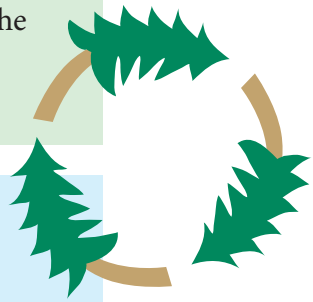
Paper and the environment

"But, what about the environment grandpa? Won't those big machines create crazy amounts of pollution?"
"They once did. Paper-making used to be a filthy business. They used huge amounts of water, in fact, for every tonne of paper a 100,000 litres of water was needed. The water was contaminated by chlorine, which was used to bleach the paper. Chlorine is poisonous for animals and plants. Water was also contaminated by small plant remains, which were spread as nutrients to rivers and lakes."
"Oh, that sounds really bad"
"Yes, but today things are different. Today the water runs in a closed system, where it is purified and recycled. The factory uses the same water over and over again, so

there is no contamination to rivers and lakes. They have also discovered how to bleach paper without the use of chlorine. Altogether this has caused a huge reduction of pollution from paper mills compared to the old days."

Paper and the environment

Paper is an environmentally friendly product. It is made from wood fibres; therefore it is part of the nature's cycle. When used, paper is thrown away. It can be recycled and eventually burned; in that way it provides an environmentally friendly energy. The energy from the paper is the solar energy which the tree collected when it was growing.



Paper and sustainable forestry

Did you know that most of the paper we use in Europe, originates from sustainable forestry in Europe? Sustainable forestry is forestry, which cultivates the forest in a way taking into account the animals and plants that live in the forests. When the forest is harvested, new trees are planted. In fact, over 30 percent of Europe is covered by forest. And Europe's forests are growing bigger every year.

"I've thought about something, grandpa."
"Yes, what?"
"I wonder what the world would look like if we had never invented paper?"
"Well, in that case we would be missing a few things, for example books. Try to think of all the good ideas that we would have missed if we had not captured them on paper."

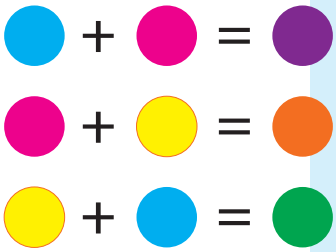
Paper and printing

"But what about books grandpa, how do the words end up on paper?"

"It happens at the printing works. In the old days there was a person who put tiny letters, made from lead, in rows on a printing plate. The plate was a mirrored image of what should be printed. It was a big job. Today we can set up letters and pictures graphically by computer, which is transferred to a printing plate."

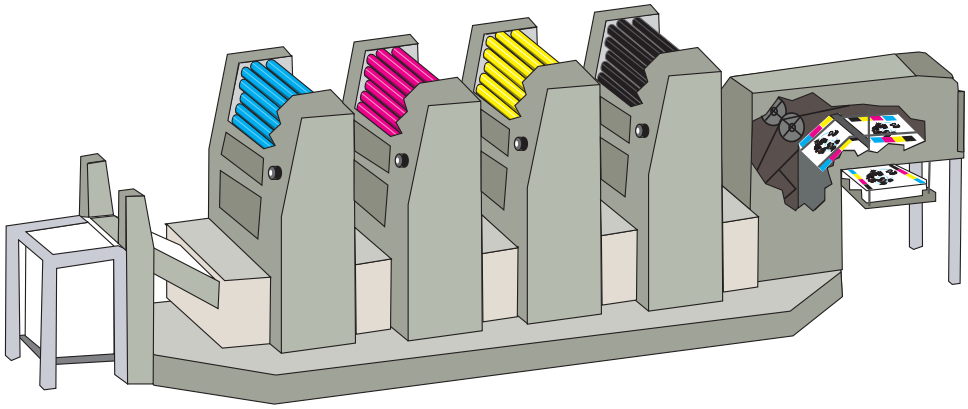
"And what happens then?"

"A printing press is a long machine which the paper passes through. Often the machine consists of four printing units with pressure plates. Each printing unit can print one colour. You use the three basic colours; blue, red and yellow - and black. Inside the printing machine, huge sheets of paper pass swiftly through the four printing units. In the first unit the colour blue is printed, in the second red, in the third yellow and finally, the black colour. And then the print is complete. This kind of printing press can print lots of paper in a very short time - and on both sides. Afterwards the printed paper is cut and made into books, magazines, or whatever it was intended for."

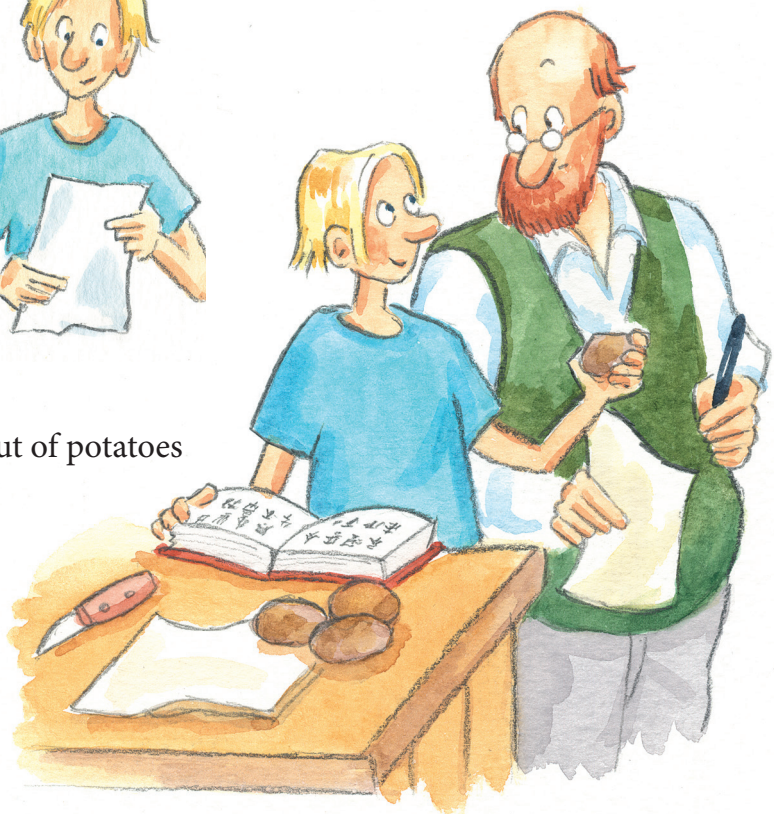


Blue, red and yellow

Did you know that you can mix all colours from the three basic colours, blue, red and yellow? And if you also use black and white, you can make your colours darker or lighter. This is what they do in a printing office. You use some special colours that are called CMYK colours. Cyan is blue. Magenta is red. Yellow is yellow. Key colour is black. The paper is white.



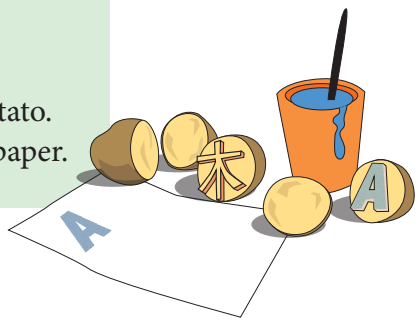
“Phew! It’s not so easy to make paper is it grandpa?”
“No, William - not when you want to make big amounts of it. But it went very well with our own small factory.”
“Do you think our paper is dry now?”
“Well, perhaps we should test it. I think I will write a letter to grandma. What will you use yours for?”



“I will carve printing blocks out of potatoes to make a potato print.”
“How do you do that?”
“Just look here. Perhaps I’ll carve a Chinese character. After all, the paper was invented in China.”

How to make potato print

- Cut a potato in two and use the flat side.
- Carve a pattern or a letter on the flat side of the potato.
- Paint the letter with a colour, and press it on your paper.



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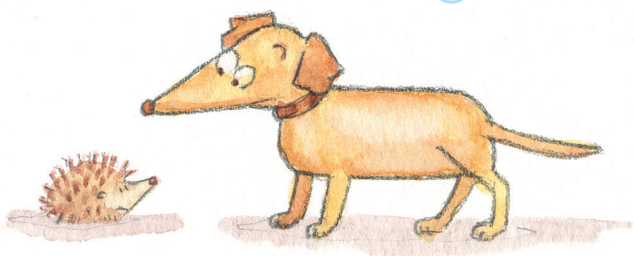

William's grandfather is a forester. He lives in a red house in the forest. Some of his trees shall be harvested and made into paper. But how do you actually make white paper out of 15 meter tall trees with bark and branches? How did people invent paper making? What has paper got to do with photosynthesis? How does printing press work? And how to make your own recycled paper? William and his grandpa take a journey into the history of paper, trees, and printing. "The story of paper, trees, and printing" can be used in science classes' from grade 4. The book covers paper, forest, forestry, wood, photosynthesis, wood fibres, paper history, recycling, the environment, the climate, paper production, printing press - and much more.

The story of paper, trees and printing is a product from www.skoven-i-skolen.dk, (Forest in School in Denmark).

English version is available from www.leaf-international.org, Learning about Forests.