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CHEMISTRY PLAYS NOSTALGIA BEHIND THE AROMA OF BOOKS

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ABSTRACT

When you walk into a library or a book store, the odor that works its way to your nostrils is a rather distinct one: the smell of old and new books. In fact, that unique smell is so loved that many avid readers still prefer physical books over the convenience of their digital versions (e-books). Books are made up almost entirely of organic materials: paper, ink, glue, fibers etc. All these materials react to light, heat, moisture and even each other over the years and release a number of volatile organic compounds (VOCs). While the blend of compounds released by any one book is dependent on the exact things that went into making it, there's only so much variation in materials. Although new books are, well, new, they still give off a distinct odor. If you hold a new book up to your nose, you'll get a whiff of paper, ink and the book binding's adhesive. However, different books smell differently, because in today's modern age, different books use different chemical processes, paper treatments and adhesives in their making. This makes it difficult to determine specific chemicals that contribute to that smell, but all new books have three things in common: paper, ink and adhesives for binding. The process of creating paper from wood pulp itself involves a variety of chemicals, many which give off volatile organic compounds (VOCs), which release into the air and create odors. Then there's ink and adhesives, which also give off smells associated with books. However, it's the chemical compositions of older books that are most interesting. Although some readers like new book smells, it is old book smells that many are the most fond of and that chemistry is easier explained because the breakdown of compounds in the paper itself causes the smell. Older books have paper that contains a lot more cellulose and lignin, which come from the paper's original source: trees. These chemicals degrade and release VOCs, releasing scents that remind us of almonds, vanilla and flowers. The researchers tested 72 books and found some 15 compounds that came up again and again. They were reliable markers for degradation. These include acetic acid, benzaldehyde, butanol, furfural, octanal, methoxyphenyloxime and other chemicals with funny-sounding names. A book's smell is also influenced by its environment and materials it encounters over the course of its life (which is why some books have hints of cigarette smoke, others smell a little like coffee and still others, cat dander). You can't judge books by their covers, but the researchers think you can learn a lot from their odor. They're developing a method for determining the condition and age of books and other paper documents by using special "sniffing" equipment to analyze the blend of VOCs. They hope that this study of "degradomics" can help libraries, museums and archives assess and monitor the health of their collections and store and care for them accordingly.

KEYWORDS: VOC, Adhesive, Water repellant, Bleaching agent, Cellulose, Lignin.

INTRODUCTION

Books, both new & old, will give off several hundred volatile organic compounds (VOCs). These compounds have a variety of origins - some are the products of degradation, whilst others are the result of the type of paper, binding adhesive and printing ink used in the manufacture of the book. The emission of these compounds can also be used as a tool to assess degradation & condition of books.

New books: The odour of new books is contributed to by a mix of volatile chemicals which originate from the adhesive, ink and the paper treatment methods used in the book.

Adhesives: Modern day book binding adhesives are often based on 'co-polymers' such as that shown here. Some VOCs may originate from these compounds. In the paper-making process, the paper is treated with a variety of chemicals, to achieve desired properties. Some of these chemicals could contribute to the release of VOCs. Additionally, petrochemicals used as solvents for inks can also contribute.

Old books: Over time, the gradual breakdown of the cellulose & lignin contained in paper leads to the production of large numbers of different organic compounds. No single chemical causes the odour of books. It's a result of a complex mix of volatile

chemicals produced by chemicals used in their manufacture, as well as the gradual degradation of the chemicals within the paper. Everyone's familiar with the smell of old books, the weirdly intoxicating scent that haunts libraries and second-hand book stores. Similarly, who doesn't enjoy riffling through the pages of a newly purchased book and breathing in the crisp aroma of new paper and freshly printed ink? As with all aromas, the origins can be traced back to a number of chemical constituents, so it can be examined the processes and compounds that can contribute to both. As far as the smell of new books goes, it's actually quite difficult to pinpoint specific compounds, for a number of reasons.

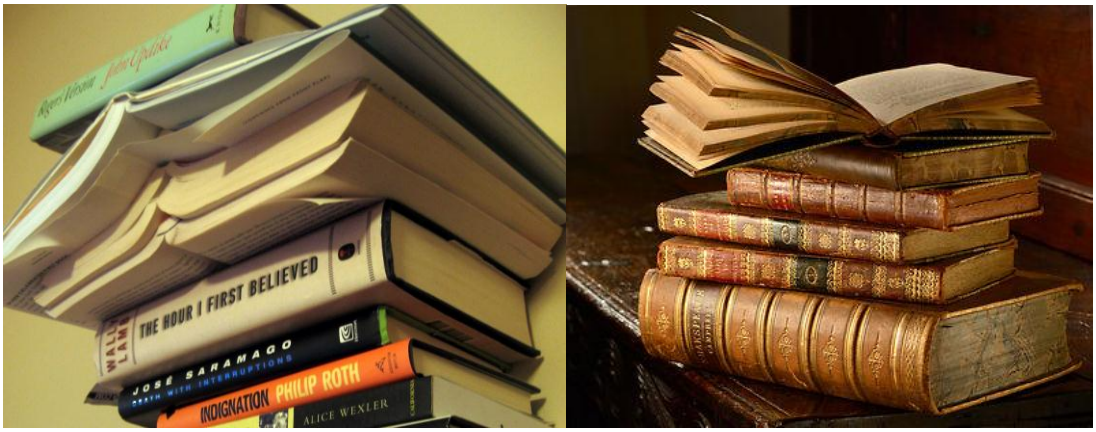
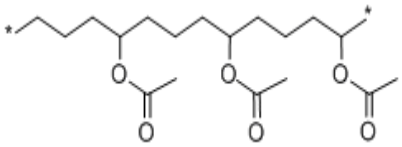
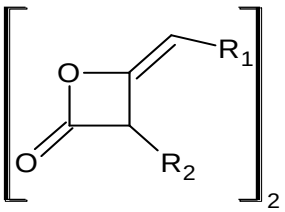


Figure-1: New Books & Old Books

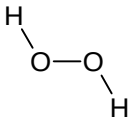
Firstly, there seems to be a scarcity of scientific research that's been carried out on the subject – to be fair, it's understandable why it might not exactly be high up on the priority list. Secondly, the variation in the chemicals used to manufacture books also means that it's an aroma that will vary from book to book. Add to this the fact that there are literally hundreds of compounds involved and it becomes clearer why it evades attribution to a small selection of chemicals.



Vinyl acetate ethylene (adhesive)



Alkyl ketene dimer (aids water resistance)



Hydrogen peroxide (bleaching agent)

Figure-2: Adhesive, Water repellant, Bleaching agent

It's likely that the bulk of 'new book smell' can be put down to three main sources: the paper itself (and the chemicals used in its manufacture), the inks used to print the book and the adhesives used in the book-binding process.

The manufacture of paper requires the use of chemicals at several stages. Large amounts of paper are made from wood pulp (though it can also be made from cotton and textiles) – chemicals such as sodium hydroxide, often referred to in this context as 'caustic soda', can be added to increase pH and cause fibres in the pulp to swell. The fibres are then bleached with a number of other chemicals, including hydrogen peroxide; then, they are mixed with large amounts of water. This water will contain additives to modify the properties of the paper – for example, AKD (alkyl ketene dimer) is commonly used as a 'sizing agent' to improve the water-resistance of the paper.

Table-1: Paper pulp composition

Component	Wood	Nonwood
Carbohydrates	65–80%	50–80%
Cellulose	40–45%	30–45%
Hemicellulose	23–35%	20–35%
Lignin	20–30%	10–25%
Extractives	2–5%	5–15%
Proteins	<0.5%	5–10%
SiO_2	<0.1%	0.5–7%

Many other chemicals are also used – this is just a very rough overview. The upshot of this is that some of these chemicals can contribute, through their reactions or otherwise, to the release of volatile organic compounds (VOCs) into the air, the odours of which we can detect. The same is true of chemicals used in the inks and the adhesives used in the books. A number of different adhesives are used for book-binding, many of which are based on organic 'co-polymers' – large numbers of smaller molecules chemically chained together.

As stated, differences in paper, adhesives and inks used will influence the 'new book smell', so not all new books will smell the same – perhaps the reason why no research has yet attempted to definitively define the aroma. An aroma that has had much more research carried out around it, however, is that of old books. There's a reason for this, as it's been investigated as a potential method for assessing the condition of old books, by monitoring the concentrations of different organic compounds that they give off. As a result, we can be a little more certain on some of the many compounds that contribute to the smell. Generally, it is the chemical breakdown of compounds within paper that leads to the production of 'old book smell'. Paper contains, amongst other chemicals, cellulose, and smaller amounts of lignin – much less in more modern books than in books from more than one hundred years ago. Both of these originate from the trees the paper is made from; finer papers will contain much less lignin than, for example, newsprint. In trees, lignin helps bind cellulose fibres together, keeping the wood stiff; it's also responsible for old paper's yellowing with age, as oxidation reactions cause it to break down into acids, which then help break down cellulose.

'Old book smell' is derived from this chemical degradation. Modern, high quality papers will undergo chemical processing to remove lignin, but breakdown of cellulose in the paper can still occur (albeit at a much slower rate) due to the presence of acids in the surroundings. These reactions, referred to generally as 'acid hydrolysis', produce a wide range of volatile organic compounds, many of which are likely to contribute to the smell of old books. A selected number of compounds have had their contributions pinpointed: benzaldehyde adds an almond-like scent; vanillin adds a vanilla-like scent; ethyl benzene and toluene impart sweet odours; and 2-ethyl-1-hexanol has a 'slightly floral' contribution. Other aldehydes and alcohols produced by these reactions have low odour thresholds and also contribute.

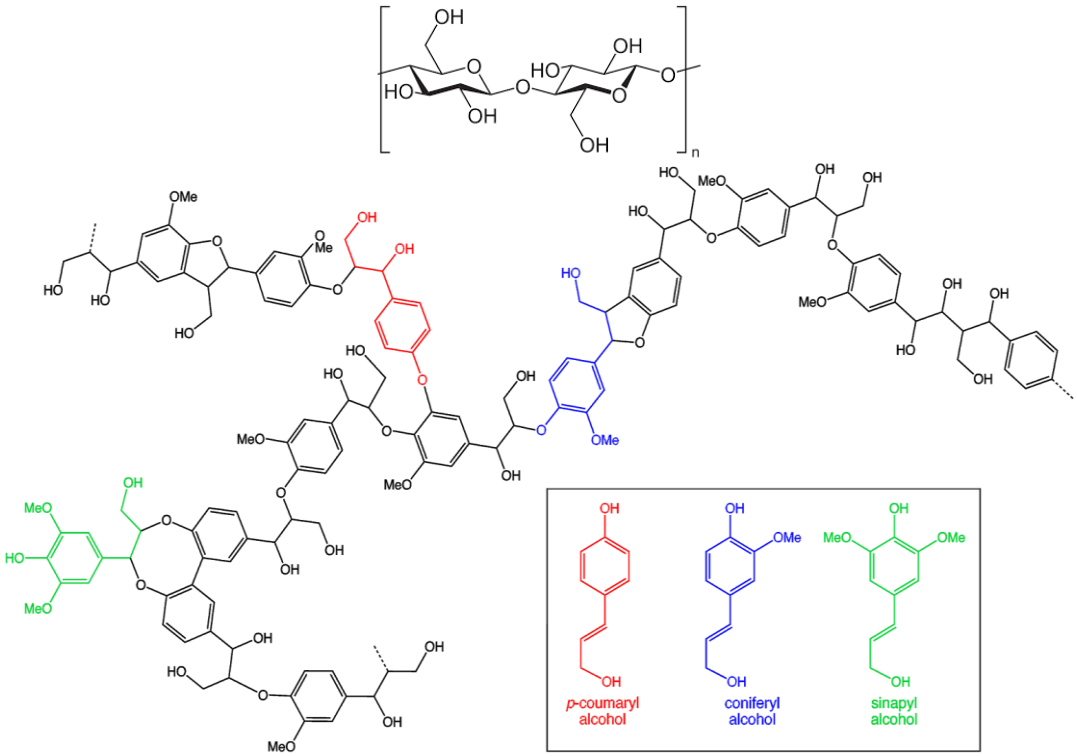


Figure-3: Cellulose & Lignin

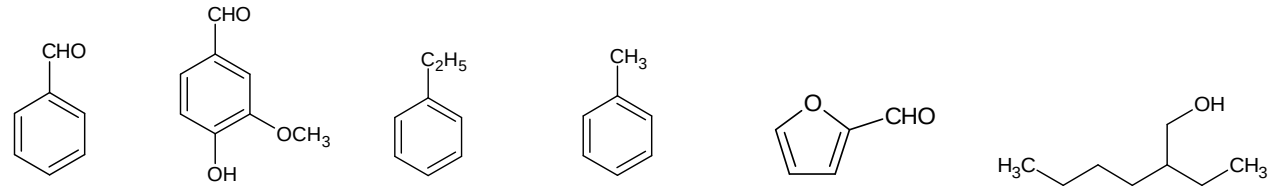
Other compounds given off have been marked as useful for determining the extent of degradation of old books. Furfural is one of these compounds. It can also be used to determine the age and composition of books, with books published after the mid-1800s emitting more furfural and its emission generally increasing with publication year relative to older books composed of cotton or linen paper. So, in conclusion, as with many aromas, we can't point to one specific compound, or family of compounds, and categorically state that it's the cause of the scent. However, we can identify potential contributors, and, particular in the case of old book smell, a number of compounds have been suggested. If anyone's able to provide further information on 'new book smell' and its origins, it would be great to include some more specific details, but I suspect the large variations in the book-making process make this a tough ask.

In the meantime, if you can't get enough of that new book or old book smell, you might be interested to learn that one company has produced a range of aerosols designed to replicate them, although they no longer seem to be available to purchase. Alternatively, if you yourself would rather smell like a book, it seems the

aroma is also available in perfume form. Old books have a sweet smell with notes of vanilla flowers and almonds, caused by the breakdown of chemical compounds in the paper. The smell of new books depends on chemicals used in their manufacture and this can vary from volume to volume. British chemistry teacher created the info graphic to demystify the differing smells of old and new books and to reveal their chemical compounds. The smell of books that lingers in second-hand book stores is distinctive, but it is hard to know exactly what creates the nostalgic aroma.

Old books have a sweet smell with notes of vanilla flowers and almonds, caused by the breakdown of chemical compounds in the paper, while new books smell like they do because of chemicals used in their manufacture. The anonymous blogger said the chemical breakdown of compounds within paper leads to the production of 'old book smell'. Paper contains cellulose and small amounts of lignin - a complex polymer of aromatic alcohols – and finer papers contain less lignin than cheaper material like newsprint. Old book smell' is generated by the breakdown of cellulose and lignin in paper, which produces organic compounds.

Benzaldehyde adds an almond-like scent, vanillin smells of vanilla and ethyl hexanol has a 'slightly floral' scent. Ethyl benzene and toluene, which are also produced give off impart odours. These volatile organic compounds are created by reactions known as 'acid hydrolysis' and together make up the smell of old books along with other alcohols produced by the reactions. No-one is sure of exactly which chemical compounds contribute to 'new book smell'. The scent differs from book to book as different chemicals are used in the making of different volumes. It is thought the smell derives from three main sources: The paper, inks used to print the book and the adhesives used in book binding. Lignin is what makes paper yellow with age because oxidation reactions cause it to break down into acids, which then help break down cellulose. The smell of old books comes from chemical degradation and a number of compounds have been pinpointed.



Benzaldehyde (Almond-like) | Vanillin (Vanilla-like) | Ethyl benzene (Sweet odour) | Toluene (Sweet odour) | Furfural (Almond-like) | 2-ethyl-1-hexanol (Floral)

Figure-4: Volatile Organic Components (VOC)

Benzaldehyde adds an almond-like scent, vanillin smells of vanilla and ethyl hexanol has a 'slightly floral' scent. Ethyl benzene and toluene, which are also produced give off sweet odours. These volatile organic compounds are created by reactions known as 'acid hydrolysis' and together make up the smell of old books along with other alcohols produced by the reactions. Some compounds such as furfural are useful to determine the damage to antique volumes. It can be used to date tomes as well as to determine their composition. Books published after the mid-1800s emit more furfural than older volumes which are composed of cotton or linen paper.

Benzaldehyde adds an almond-like scent, vanillin smells of vanilla and ethyl hexanol has a 'slightly floral' scent. Ethyl benzene and toluene, which are also produced give off sweet odours. It is thought that 'new book smell' derives from three main sources: the paper, inks used to print the book and the adhesives used in book binding. Lots of chemicals are used to make paper, which is largely manufactured from wood pulp. Chemicals such as sodium hydroxide – which is often known as caustic soda – can be added to decrease the acidity and cause fibres in the pulp to swell. The fibres are bleached with a mixture of other chemicals including hydrogen peroxide and are mixed with water, which itself contains additives. Some of these chemicals react and release volatile organic compounds into the air, which create the distinctive smell that varies from book to book depending on the adhesives, ink and paper used.

1. Books are made up of paper, adhesive, and ink. When these materials degrade over time, they give off organic volatile compounds, which in turn produce a smell that's appealing to readers. The reason the smell is so appealing may be because it has a hint of vanilla. The scientific explanation for the vanilla-ish scent is that almost all wood-based paper contains lignin, which is closely related to vanillin.
2. The smell of books might actually remind you of things. The olfactory bulb is part of the brain's limbic system, which is associated with memories and feelings. When you first smell a new scent, your brain links the smell with an event, a person, a thing, or a moment. When you smell the same scent again, your brain conjures up the linked memory. It may not always be an explicit memory, it could just be an emotion or a feeling.
3. Books remind people of *all good things*. Now for an utterly unscientific, sweeping generalization: books are the absolute best-smelling thing in the world, because books appeal to explicit and implicit memory. Books always remind people of wonderful moments they've experienced *and* they make people feel inexplicably, emotionally *good*. I've had friends tell me the smell of

books makes them feel calm and safe, as if they're in a sanctuary, because they're reminded of their school library. Other people say the smell of books fills them with anticipation, because they're reminded of the stories they eagerly awaited as children. I've heard the smell of books is comforting because it reminds people of being warm, curled up, and relaxed. I've even heard the smell of books is liberating, because it harks back to moments of free, uninterrupted, leisure time.

CONCLUSION

Different people seem to like different smells when it comes to books. There are those people who like the smell of old books and there are others who like the smell of a book being opened for the first time. The aroma that emanates from books is caused by a number of chemical reactions – not just the sweet smell of great prose!

Old books have a sweet smell with notes of vanilla flowers and almonds, which is caused by the breakdown of chemical compounds in the paper, while new books smell like they do because of the carious chemicals used when they are manufactured. The chemical breakdown, over a period of time, of the compounds within paper produces the smell. Paper consists of cellulose and small amounts of lignin (a complex polymer of aromatic alcohols). Paper that is even finer contains less lignin than cheaper materials, like the paper used in newspapers. Lignin is the same chemical that makes the color of old paper yellow, as it becomes oxidized over a long period of time to break down into acids, which in turn break down to cellulose. Now, let's get to the chemistry of that remarkable smell.

Old Books: The chemicals responsible for the sweet smell of old paper are benzaldehyde, vanillin, ethyl hexanol, toluene and ethyl benzene. These chemical reactions, which produce such volatile compounds, are called 'acid hydrolysis'. Chemical reactions spanning a considerable amount of time make these compounds produce sweet odors.

New Books: The smell of new books can be attributed to three factors: the paper itself (it smells good because of the chemicals used to manufacture it), the ink used to print the book, and the adhesives used in the process of book-binding.

If we look at the smell of paper itself, we would find that a lot of chemicals are used to manufacture paper (although it is largely manufactured from wood pulp). Furthermore, there are certain chemicals, such as sodium hydroxide (caustic soda), that are added to the paper to diminish its acidity and swelling of the fibers of the wood pulp used in the paper.

It's true that the content of any book is the real purpose of purchase, but I can assure you, if you read a lot, then you are almost certainly a fan of that legendary book smell too!

REFERENCE

http://www.dailymail.co.uk/sciencetech/article-2647333/Why-old-books-smell-good-Infographic-reveals-complex-chemistry-comforting-scent-yellowed-pages.html