An introduction to the technicalities of paint.

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“When painting the faces of young persons, use the yolk of the egg of a city hen, because they have lighter yolks than those of country hens.”

- Cennino Cennini (c. 1360 - 1427)

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Introduction

A specific material or tool can mean an important breakthrough or a key element for an artist practice in whatever medium, therefore also for painters. A beautiful example in which a material fuels a breakthrough and becomes key, is the example of Lucian Freud and his relation with Cremnitz white. “It was so crucial for paint to become flesh that when he discovered a heavy lead based paint: Cremnitz White*,* it so suited the way he saw things, he could not create without it. Cremnitz White helped to give Freud his look of pasty, lifting bodies, lying in stained and damaged rooms .”[1] Despite Freud’s great technical skills to work with the paint exactly how he wanted, he knew that his material had a significant part in his successful practice and most important, he did not deny that.

To be able to make use of certain materials that may create a breakthrough in an artist practice, it can be fruitful to first obtain some material knowledge before there is experimentation. Binders can be toxic, different paints require different thinners and a minimal difference in the color of a pigment can mean a big difference in its properties.

There is an abundance of paints and painting materials, not to speak about properties per material. The amount is overwhelming and can be confusing. To offer some handles, to try to prevent unhealthy situations and possible early wear of a work and to try to make the painter perhaps more aware of the attributes of paint, the document will examine the paint from three different angles. The first angle discusses a few historical events of the material. It highlights a number of groundbreaking developments and their consequences. The following chapter delves into the realm of pigments. It has its focus on how the centuries old powder functions by discussing the several pigments attributes and basic technicalities. The last chapter discusses the role of a binder in a paint and deals more specifically with oil as a binder.

The document, as it is now, functions as an introduction for the young or beginning painter. It scratches the surface of technical and historical facets of the material. All the properties that are discussed can be further deepened to such an extent that they individually can function as a paper or even a book. Although the world of paint is immense and too magnificent to even try to cover in one thesis, the urge was there to touch upon all the aspects that are discussed. The goal is to keep increasing it and process all the technical knowledge that has been gained with regard to painting materials. It can be said that it is perhaps never finished, materials are always evolving.

[1]https://www.youtube.com/watch?v=Qm3nNkCdNG8&list=PL6akTCo7oJaRPlsGdyyGsiis7xOClGYNQ&index=89, 0:00 - 0:34

Lucian Freud, Man in a Chair, 1983-1985, Oil on Canvas, 120,7 x 100,4 cm, Thyssen-Bornemisza Collection, Madrid, Spain.[2]

Lucian Freud's painting language has known an interesting change at a certain point in his career. The visual change was practical in nature. Freud changed his painting position from sitting to standing and swapped his brushes from sable brushes to hogs hair.[3] According to Freud, he needed the change of position to develop his style and the change of the brush was to get rid of the 'Germanic' quality with which people associated his work. Due to two simple practical changes, the work acquires a different intensity and the work seems to be even more about the intense observation for which the painting process of Freud is known.

[2] http://lucianfreud.com/lucian-freud-archive---paintings-1984-to-1985.html

[3] https://www.theartstory.org/artist/freud-lucian/artworks/#pnt_3

Historical Highlights

When one thinks about paint and its history, there can easily be many preconceptions about its development. It can seem as a material that has made a very slow development over a long period of time. This preconception is very understandable and partly true, but the development has its interesting highlights and beautiful breakthroughs, as well as huge rapids in the development. Its history can say more than just a development of paint. The development mirrors the conceptual capacity of the human brain and with every discovery we learn more and more about the perhaps much greater intellect of our ancestors than we once thought they had. History of a certain material can make the painter look at the material from a different angle. It can create a basis where further material knowledge finds a solid foundation and where materials can be put into perspective.

The chapter covers the historical highlights, breakthroughs and developments that function as milestones and are astonishing for their ability to refute the present obviousness of paint.

Blombos Cave

The first breakthrough and perhaps the biggest highlight in the history of paint is its very first use. At the same time this event is complicated. To this day new discoveries are often made and indicate that old theories do not come close to the truth. Whether we will ever find the evidence, and therefore be given the opportunity to determine when the very first paint was used is impossible to say. This could feel helpless to some, but at the same time could stimulate our capacity of fantasy and perhaps give the motivation to continue the search for new evidence in order to get closer to the truth.

What we have evidence of is the discovery of 350.000 year old pigments in the Twin Rivers Cave in Zambia, as well as the abalone shells full of ground ochre and charcoal from 100.000 years ago, found in the Blombos Cave in South Africa, together with grinding cobbles and bone spatulas in 2008.[4] One would expect paintings or painted objects of any kind to go with these materials, but those are not found. Scientists can not prove if art was the purpose for the materials. The professor and director of the Centre for Early Sapiens Behaviour (SapienCE), Christopher Henshilwood, states the following: "It's possible the paint was used to paint bodies, human skin. It could have been used to paint designs on leather or other objects. It could have been used for paintings on walls, although the surfaces of southern African caves are not ideal for the long-term preservation of rock art.”[5]

The Blombos Cave discoveries are groundbreaking. Together with other discoveries, such as the first examples of shell jewelry found at the Skhul Cave in Israel, the discoveries create serious doubt about the idea that the history of paint, painting, and therefore conceptual thinking starts in the caves of Europe.

The absence of the painted objects attract attention. The materials survived 100,000 years, but the painted surface is, until today, nowhere to be found. The absence implies the precarious career of painted surfaces. It somehow emphasizes the transience of a painted surface and the finds highlight the infinite lifespan of pigments. Perhaps an interesting given to keep in mind as a painter.

The earliest use of paint that has been found is located in the caves of Australia, Indonesia and Europe. These cave paintings have been set at an age of 40.000 years old. The most recent discovery is the cave painting in a limestone cave in Borneo and may be the oldest cave painting that is found yet. It was found by the archeologist Maxime Aubert and his team. They used a special

[4] https://www.bbc.com/news/science-environment-15257259

[5] https://www.bbc.com/news/science-environment-15257259

technique to indicate the age of the painting. “Aubert’s team found calcite crusts near the rear of the painted animal and used a technique called uranium series analysis to date them to at least 40,000 years old. If the measurement is accurate the Borneo paintings may be 4,500 years older than depictions of animals that adorn cave walls on the neighboring island of Sulawesi.”[6]

New discoveries in the realm of cave paintings are not uncommon. Every time a discovery is made it makes a small or big difference in our idea of history of mankind. Famous discoveries and great examples are the caves of Chauvet, Lascaux, Altamira and Sulawesi. These discoveries provided a lot of new knowledge about the history of the materials that were used and the developments that mankind has made. In these paintings we see pigments that were extracted directly from the earth, such as yellow and red earth or ash from fires, as well as blood, sap, berry juices, dried plants and roots. The binding materials that were used to create a pasty substance were set at animal fat, saliva, urine and water.

It is important to mention is the effort that has been made to obtain sustainable pigments and materials. With the discovery of mine tracks, scientists discovered that painters traveled many many miles, 25.000 years ago, for the iron oxide pigments famous for their durability.[7] This indicates the awareness of the importance of the quality of materials.

Pigment expansion

The preconception of a slow development of pigments that is mentioned in the introduction, could easily be applied on the period after the earliest cave paintings. Current research has shown that the pigments remain the handful of colors until 1500 b.C. In that year, the palette expansion starts with the discovery of burnt colors. They discovered, most likely by the invention of pottery, that earth pigments changes color when heated. Around the same period the Egyptians and Ancient Greeks knew several other pigments, such as: vermilion, malachite, azurite, zinc white, white lead and lead menia.[8] These pigments were not all originally from Egypt and ancient Greece. The Egyptians and Greeks imported their pigments from Asia and all over Europe; this emphasizes the long journeys that pigments made.

The Egyptians not only expanded their pigments during this period, they developed new ways to mix their pigments with eggs and started painting on plaster. A technique that is later called tempera. This development can be seen as very progressive and will mean a lot to the history of paint. The Greeks and Romans developed their techniques and style to such an extent that further technical development only takes place towards the time of the Renaissance with the invention of oil paint.

The realm of pigments and paint develops with jerks and makes a next interesting step around 900: the discovery of an almost magic pigment.

Ultramarine blue

In the history of color blue, appears to be controversial. The color blue often comes into western art history only in the Middle Ages. According to Monica Rotgans, artist, color expert and author of the series: 7 Colours Project - Verf, het gezicht van de kunst*,* this is too limited and should be seen as Western reasoning. In the first book of the three-part series: *Blauw Groen - Verf, het gezicht van de kunst* (Blue Green - Paint, the face of art) she states that the limited view excludes thousands of

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[6] https://www.theguardian.com/science/2018/nov/07/worlds-oldest-figurative-painting-discovered-in-borneo-cave

[7] ED059 The colorful history of paint, p.1

[8] Het Kunstschilderboek, C. Herenius & D. Kraaijpoel, p.56

years of non-western art, that functioned as the breeding ground for European arts.[9] The great loss of color encouraged this limited thinking. Time, nature, religious and cultural violence and vandalism have all contributed to this loss of color. Fortunately there is natural science today. Thorough research has made it increasingly clear how much color, including blue, must have existed in the classical world. The buildings, palaces and statues were multicolored objects instead of the gray, monotonous ruins as we see them now.

Despite the fact that blue was not a new color in this period, as people thought it was, the arrival of Ultramarine blue had impact. After Lapis Lazuli or Lazarium Ultramarinum was found in the Hindu Kush*,* a western spur of the Himalayas located in Afghanistan*,* its symbolic value exploded. The stone was seen as the earthly housing of the four elements: water, fire, earth and air. Lazurite*,* the blue aluminium silicate was seen as water, white calcite seen as earth, the pyrite particles as fire and the sum of the parts as air. Lapis Lazuli was the color of the hereafter and the throne of God.[10] According to Cennino Cennini *(approx. 1360),* the first painter that revealed all the facets of painting in his book called: *Il libro dell'Arte,* ultramarine blue was the most perfect color of all. He states that the color is more beautiful than you could describe in words. In his book he explains the characters of many pigments and explains how they are made or dealt with. All the pigments are described in a couple of sentences but the description of *Ultramarine blue* covers three full pages to emphasize the importance of it. He encourages every painter to use it. Ultramarine will serve the painter well.

Not unlike other pigments, Lapis Lazuli has known a great travel history. The stone traveled from its source, the Hindu Kush, all over the African and Eurasian continents. These journeys were made possible by ancient intercultural contacts and trade routes. Therefore, ultramarine did not only become a sacred color in European cultures. It had, and still has, various sacral values for several cultures and religions outside of Europe.

'Jan van Eyck's invention'

From the Egyptians and the Greeks*,* until 'Jan van Eyck's invention', tempera was the technique that determined painting. Tempera was a technique that made use of eggs. Painters used the white, the yellow or the whole egg as binding materials. Painters that did murals used a different type of tempera; casein tempera*,* which made use of cheese curd as a binder.

Tempera can be seen as a difficult material. Because of its quick drying attribute, painters only could prepare a small amount of paint, which made painting a slow process. Corrections were hard to make and the style of painting was forced to be stroke by stroke, without smooth color transitions.[11] But the use of egg as a binding agent did not exclude the use of oil in paint. Oil was added to the egg mixture to be able to work longer with the paint, or when the painting was finished, as a varnish function, to give the painting a softer appearance. It was already the state of affairs far before Jan van Eyck 'invented' oil paint. But why did the first art historian, furthermore painter and architect Giorgio Vasari (1511) stated that Jan van Eyck invented oil paint while there are various sources that proof something else, such as the manuscript; *Schedula diversarum artium,* written by the monk Theophilus*,* in 1123, in which oil paint is described and taught?

Giorgio Vasari considered an inventor someone who transformed known elements into a new formula. A misinterpretation of the original text of Vasari started the myth about van Eijck and wiped out a rich history of the use of oil in paint. Despite the fact that Jan van Eijck is not the

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9 Blauw Groen - Verf, Het gezicht van de kunst, Monica Rotgans, p.44

10 Blauw Groen - Verf, Het gezicht van de kunst, Monica Rotgans, p.75

11 Verf: 500.000 jaar verf en schilderkunst, Monica Rotgans, p38

inventor as one would define an inventor in the present, he can certainly be praised for his developments on oil painting. He invented the new way of working with oil that changed painting permanently. His smooth painted, transparent layers created an unprecedented quality and power.

Accelaration

The developments of oil paint altered the field of painting and the world and painters had the time to adapt. But as it goes, development continues at a rapid pace when everyone has had time to adjust. It accelerated on various aspects, with the nineteenth century as a development explosion. According to Monica Rotgans, the discovery of an arsenal of cheap paint substances, the rapid rise of the industrialized paint industry, the invention of the tube and the invention of the tin cylinder, were the four direct technical reasons for the radical changes in painting. Almost all the borders that painting knew faded with the arrival of the aforementioned developments that chemistry and technique made possible. The complex preparations and paints that dry out became history, and a slow painting process made place for a direct and quick way of painting without any limits. The synthetical colors flooded the market. Instead of ten tints of one color, 60 or even, in the case of yellow, 130 color tints were available. Painters discarded the old studio rules and seized the new developments with both hands, without even considering whether it could also have negative consequences.

The industry reaches a peak around 1845 with the invention of Coal Tar by Wilhelm von Hoffman and the invention of Mauve, an aniline isolated by coal tar, by his student; William Perkins. It was the start of the modern synthetic organic dye chemistry and created a real hype that increased the flood of colors. It was a dream come true, but turned out to have many consequences. Colors were not lightfast at all and changed tint after drying. The names of the paint were quickly made up and caused a lot of confusion. The names did not indicate any composition of chemicals, and so did not indicate possible toxic properties, which resulted in many disasters such as diseases and even death. The negative consequences led to a slow shift of production around 1890. Manufacturers started to develop better quality paints and were more clear about possible toxics. The powerful acceleration had to calm down and find solid ground to slowly develop the new industry of paint to the industry as it is now known.

It is captivating that the notion of durability is visible from an early stage of pigment development. Even 25.000 years ago people were concerned with the lifespan of their products, in this case their paintings. The lifespan of a product, not to mention works of art, is not necessarily a modern issue as can be read, but the modern perception shows that the fragmentation of knowledge did not benefit the awareness of the lifespan of a product. Restorers will have a difficult and ever-increasing task in preserving art. According to Birgit van Driel, a restorer that is specialized in titanium white, the rapid paint development that started in the 18th century does not make the task of a restorer more easy[12]. The media that contemporary artists use can not even be categorized sometimes. A development that may be positive in terms of progression, but do raise questions about the awareness and concerns of the lifespan of a material. One could conclude that a maker of an artwork is not as concerned about lifespan as they once were. That raises the question; why? Could it be the fact that the rapid industrial developments of artist materials excluded artists in the production proces? And that the maker became alienated from the material and therefore also the consequences associated with a material?

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[12] https://juke.nl/podcasts/met-groenteman-in-de-kast?gclsrc=aw.ds&gclid=Cj0KCQiAtf_tBRDtARIsAIbAKe2aVGxUwbxVnwrqgmBZgSLtmgSiWiQtwvRlJWZL9_zCcVXUKwUipuAaAuJxEALw_wcB

For a correct cause-effect theory many more aspects will have to be discussed, but given that the works of old masters or cave painters, who worked with lesser quality pigments, are still in good condition and that the works of some modern and contemporary artists cannot be presented upright, raises many questions that could awaken the contemporary painter. Perhaps the contemporary painter or maker may be held more liable for the lifespan of a work and therefore for its responsibility towards cultural heritage.

Jan van Eyck (ca. 1390-1441), Lucca madonna, around 1437, oil on oak panel, 65.7 x 49.6 cm, Städel Museum, Frankfurt am Main[13]

Jan van Eijck invented the new way of working with oil, that changed painting permanently. His smooth painted, transparent layers created an unprecedented quality and power.

[13] https://en.wikipedia.org/wiki/Lucca_Madonna

Pigments

The encounter with a pigment can be captivating and confusing. The question: 'what is a pigment?' is complex and relates to various aspects of its materiality. To answer the question briefly is perhaps impossible and would detract from the exciting world of pigments. The two obvious observations on pigments are no secrets and are known to almost everyone who has ever been in contact with paint; pigments are powdered substances, and they appear in a certain color. These two observations are correct but do not yet reveal anything of what a pigment actually is or how it functions.

This chapter explores the questions 'how' and 'what' on pigments and is divided according to its attributes and technicalities.

Pigment vs Color agent

The difference between a coloring agent, dye or colorant and a pigment is very significant. A dye dissolves in a binding material, a pigment does not. In a paint the primary particles of a pigment remain intact. A binding material does not get discolored when it is mixed with a pigment, it only binds the primary particles. You could say that a paint that contains pigments becomes a soup in which the ingredients stick to each other and that a painting material that contains a dye becomes one liquid in which the ingredients are fused.

There are not many products that make use of dyes. They do not have a good reputation in the realm of painting materials. Dyes have a strong tendency to fade quickly when exposed to daylight. One can imagine that this is probably the worst feature for a painting material that can be. Royal Talens emphasizes it with their small range of products that make use of dyes. Royal Talens uses colorants in only two products: Talens Ecoline (with the exception of white and gold) and Talens Water-resistant drawing ink (with the exception of white and black). The exceptions mentioned are pigmented and excellent lightfast.

Although pigments have a better reputation in terms of fading color, that does not mean they always function as one would like them to do. All pigments have their own pros and cons and a painter should choose the pigment wisely according to the desired end result. In order to make the right choices, there are several basics and properties that the painter should know.

Color Appearance

As mentioned above, pigments appear in certain colors. In this subchapter the why and the how of this appearance will be examined. To be able to do so the first encounter should be light. There will be no color in the absence of light.

Light

According to Isaac Newton's light theories, the light of the sun consists of six colors: red, orange, yellow, green, blue and violet. Together these form the light spectrum.[14]

When the light touches a surface, the light will (partly) be reflected. The intensity and the color of the reflection depends on the surface and the pigments of the object (the object, in this case, can be anything, for example a car or more obvious; a painting). The pigment, in the surface of the object, will absorb the colors of the light with exception of its own color. The color that appears, is the color that the pigment reflects. In case of a black pigment all the light will be absorbed, in case of a

[14] http://www.thestargarden.co.uk/Newtons-theory-of-light.html

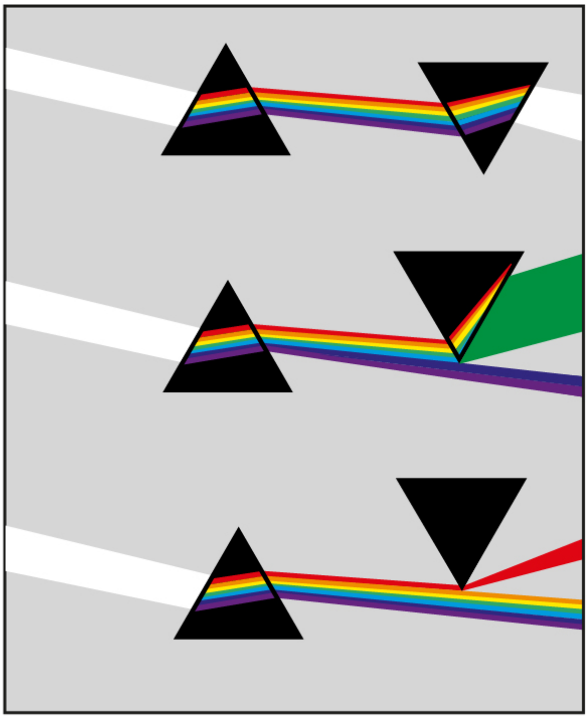

IMAGE 3. NEWTON'S CRUCIAL PRISMA EXPERIMENT

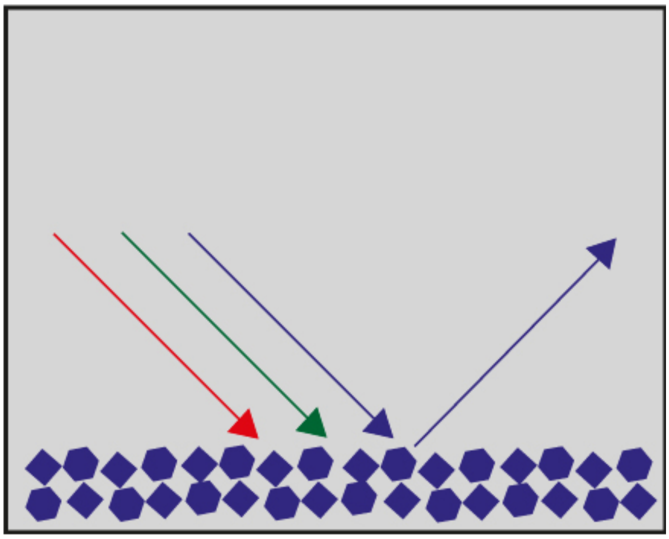

IMAGE 4. ILLUSTRATION OF COLOR REFLECTION

white pigment all the light will be reflected. In case of any pigment in between white and black, the reflection will almost show the pigments pure color. Why does the reflection not show a 100% pure color?

A color in the light spectrum has to deal with adjacent colors that have similar properties as itself in the spectrum. When the light touches the colored surface, not only the pure color of the pigment is reflected. The pigment is likely to reflect a bit of the two adjacent colors as well. In a bad case the adjacent colors are very prominent. In a perfect scenario the adjacent colors are barely visible. The amount of side colors that are reflected is all in the hands of the quality of the pigment. The purer the pigment is, the fewer side colors are reflected.

The texture of a surface will determine the amount of light that is directly reflected at the same angle. When there is a lot of light reflected at the same angle, we speak of gloss. When the light touches a rough surface, the light is scattered and so the surface will appear matte.

Lightfastness / D4303

The pigment is carrying a lot of load in terms of light. It does not function without it but can have many difficulties with it as well. Binders generally do not discolor due to daylight but pigments do. Lightfastness is the term that refers to this discoloration and is a very significant aspect in terms of producing or buying paint. It refers to the discoloration of a pigment when it is exposed to daylight. To be more specific, it is ultra violet which is fatal to the color. The degree of discoloration is due to the chemical composition, in other words, the molecular structure. The molecules can change form or break apart after prolonged pressure of light. The effects of the pressure differ per type of pigment. Organic pigments can fade completely, where inorganic pigments only darken.

After a pigment is produced, the lightfastness should always be tested. The manufacturer aims for the best pigment but can not perfectly predict the outcome in terms of lightfastness, so this has to be measured. It is measured with a measuring method based on scientific norms. The standard for this objective measurement is called D4303 and is initiated by ASTM (American Society for Testing and Materials). The standard that the American institute has created does not function as a law for paint manufacturers. Most manufacturers have their own standards for testing, which results in varying denotations per brand as can be seen in image 5. To avoid unwanted surprises, it is advisable that the painter always tests the paint him/herself.

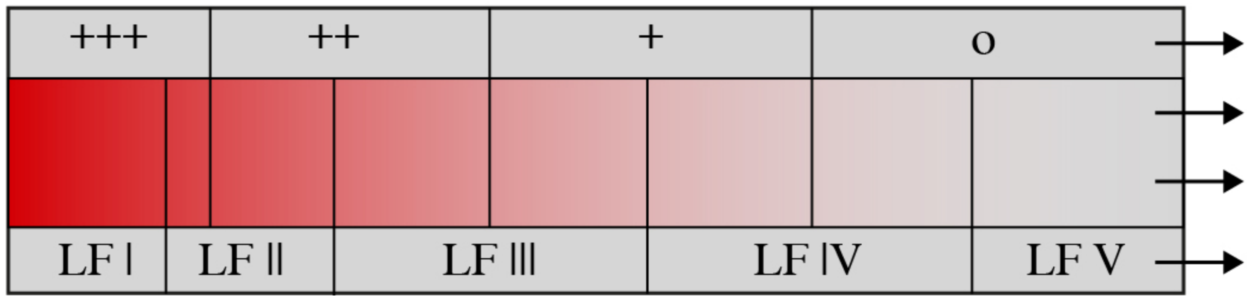

IMAGE 5. AN ILLUSTRATION OF A CLASSIFICATION DIAGRAM. THE UPPER PART IS *ROYAL TALENS'* DIVISION, THE LOWER PART IS ASTM'S DIVISION

Tinting Strength

Light reveals the colors but does not determine the tinting strength of a pigment. The term refers to the power of the color to change an other color while mixing it. When a reference is made to the tinting reducing capacity of a paint, it is about whitening a color.

According to Herenius and Kraaijpoel, the strength is determined by three points:

- The chemical composition of a pigment
- The purity of a pigment
- The size of the primary particles of a pigment[15]

It can be seen that the pigments purity not only has to do with light but with the strength as well. To give an example for the strength of the tint, Herenius and Kraaijpoel use yellow ochre. There are two yellow ochres; the natural yellow ochre and iron oxide yellow, made in a factory. Both pigments are yellow because of iron oxide, but the natural version has a weaker tinting strength. This is due to the natural pollution that yellow ochre contains. For the size of the primary pigment particles, the statement is short and simple for now; the smaller the primary particles are, the stronger the tinting strength is.

[15] Het kunstschilderboek, Kraaijpoel & Herenius, p.60

Peter Doig, Man Dressed As Bat, 2007, Oil on Linen, 300 x 350 cm[16]

Peter Doig's *Man Dressed As Bat* was created by allowing rain and weather into the studio of Doig, by a leak. As one can see, the rain has had a visual effect on the paint. It gives the work a drizzly character that seems to work very well with the subject of the painting. Despite the good image, questions can be asked about the technical effect of the rain on the paint. How will the pigments and binders react to the chemicals in the rain in the long term?

[16] https://www.bbc.co.uk/programmes/p01fjxhg/p01fjx72

Particles

The primary particles of pigments have already been mentioned a few times without further definition, but have a large share in some of the pigment properties. Pigments appear in a powdered substance, as was established in the introduction. Those powdered substances exist out of small grains that are visible with the eye. These grains can easily be made smaller after which the smaller grain is still not the particle that is referred to. When the smallest, still observable grain is placed under a microscope, it can be seen that this grain consists of even smaller particles that stick together. To understand pigments and its attributes, these are the primary particles that should be discussed.

Size

The unit in which the particles are measured is written as; µm. µm is one millionth of a meter, a micro meter; a micron. The diameter of the primary particle is in between 0,1µm and 5µm. If the primary particle is further reduced, the properties of the pigment will change and so the pigment will disfunction. There are many pigment properties that are determined by the particle size. The most important are the light scattering properties.

The first table in the appendix gives an example of the sizes of pigments.

Form

The form of a particle is not necessarily round as can be assumed considering the appearance of the powder. There are various shapes. They can be rod, block, spherical, plate or amorphous shaped. One pigment exists out of one type of primary particles, but to make it difficult, these particles can be connected in two ways. The grains that consist out of the primary particles can be called aggregates or agglomerates. Aggregates consist of particles that are connected together via the sides and agglomerates via the corners or ribs.

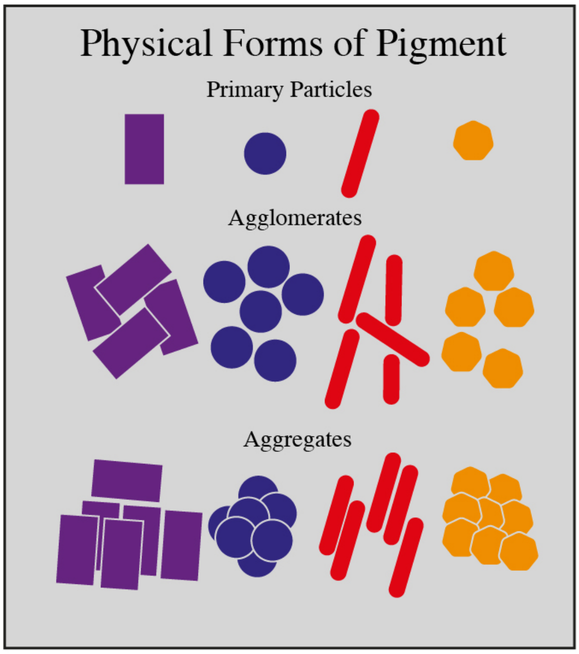

IMAGE 6. ILLUSTRATION OF PARTICLES

In a paint it is needed that all primary particles are wrapped, as much as possible, in a certain amount of binding agent. To make this possible, the aggregates or agglomerates need to be separated to a certain extent, before they can function in a paint. The separation of those grains is done by dispersion.

Dispersion of the grains is a delicate task. It is important that the grains become smaller, but they must not be too small. When a grain in a paint becomes smaller, the paint will gain opacity and tinting strength. It simply has more particles to cover the surface. But when the grain becomes too small, it will decrease those two properties. A particle that is too small will absorb the light different than it should do and therefore will have trouble with reflecting it.

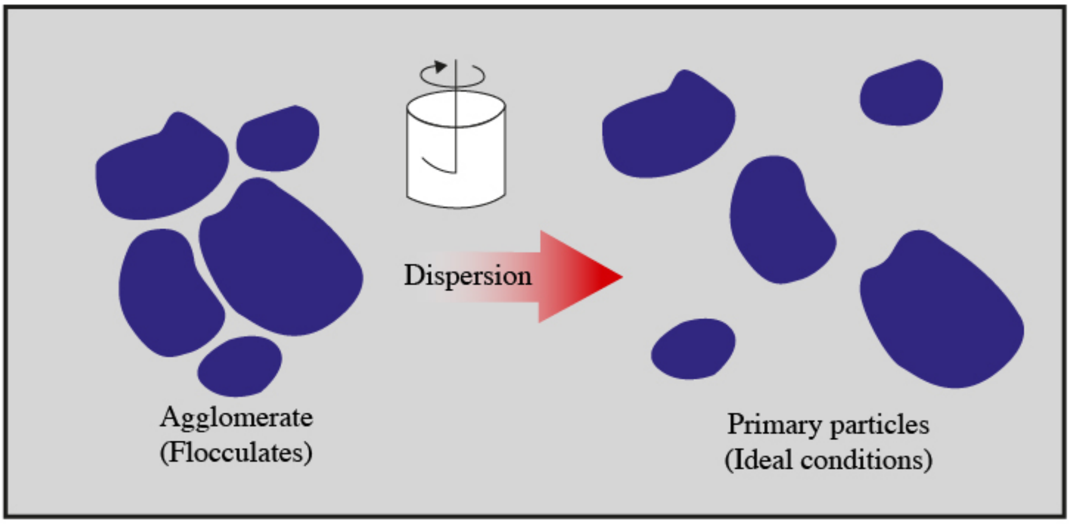

IMAGE 7. ILLUSTRATION OF DISPERSION

Hiding power

Transparency refers to the light transmittance of a paint. The paint covers the surface with a color, but the surface remains visible. The opacity or hiding power of a paint refers to the opposite of light transmittance. When an opaque paint is applied, the surface underneath becomes invisible. The degree of transparency or opacity is a prominent attribute of paint and pigments. Wall paint is often expected to be as opaque as possible, but expectations vary for artists' paint; for example, for painting in layers; referred to as glacing, the paint must have transparent properties.

The opacity or transparency of a paint depends on the average size of the pigment particles, the thickness of the paint layer, the pigment content and the refractive index. In addition to these factors, the pigment itself also has its hiding power that contributes to that of the paint. Certain pigments simply have more hiding power than other pigments. *Het Kunstschilderboek* illustrates this well. The difference between cadmium red and carmine red is given as an example. When a surface is covered in cadmium red, the light will be reflected at the upper part of the painted surface. The light does not enter the layer of paint and therefore does not reflect the surface underneath. The opposite is done with carmine red. The light does enter the layer of paint, so not only carmine red is reflected, but also the surface under the painted layer.

From this example it could be concluded that one is an opaque paint and the other a transparent one, respectively, but the example ignores the other facets on which the transparency or opacity depends. If both paints were applied in the same thickness without any dilution, the conclusion would be right but in many cases, a medium is involved in the process of painting. A paint that is applied in a thin layer does not have the ability to absorb and reflect all the light. The same applies to a highly diluted paint; the particles are further dispersed by the diluent which creates an increased distance between particles, and so the light will be reflected unobstructed by the surface.

In short, pigments can have certain properties in the range of opacity but that is no guarantee for a transparent or opaque paint. An opaque pigment can function in a paint that is used for transparency and vice versa. The term that is inextricably linked to the transparency of a paint and the aspect that has the biggest influence is the refractive index and is discussed in the following subchapter.

Refractive index

Although the refractive index (RI) is part of the chapter ‘Pigment’, the term is just as important for the binders or any substance that has contact with light. It is the physical measure that is found to indicate how strongly a light beam is refracted or scattered when it enters a substance from the air. The extent to which the light beam is refracted determines the intensity of the color. It is a fact that as the refraction increases, the intensity of the reflected light (the color) also increases. The more refraction, the higher the RI.

The RI of air is 1,0 and functions as the zero point. In terms of oil, acrylic or gouache paints, the RI of a layer of paint is determined on the RI of the pigment in combination with the RI of the binder. In terms of water color the binder does not count, it is the vehicle in combination with the pigment that determines the RI in that case. The ratio between the two digits is simply referred to as the RI Ratio. The further apart the digits are, the higher the RI Ratio is and the more hiding power or opacity the paint gains.

To understand the RI and the RI Ratio may be helpful to better understand what happens with the paint in a painting. Problems can be solved or interesting effects can be achieved. For example, it can happen that the light is refracted stronger in some places than in others in the painting. These places appear more matte. This is the result of a binder that quickly disappears in the vehicle. The tops of the pigment are exposed to the light without being wrapped in a binder and so the light is refracted stronger. Those places can be fixed by applying a small resin layer to cover the exposed pigments. The resin functions as a substitute for the binder. Like this, the RI Ratio’s are brought back to equal levels.

The second and third table in the appendix give an overview of the RI’s of pigments and binders. Image 8. visualizes two refractions.

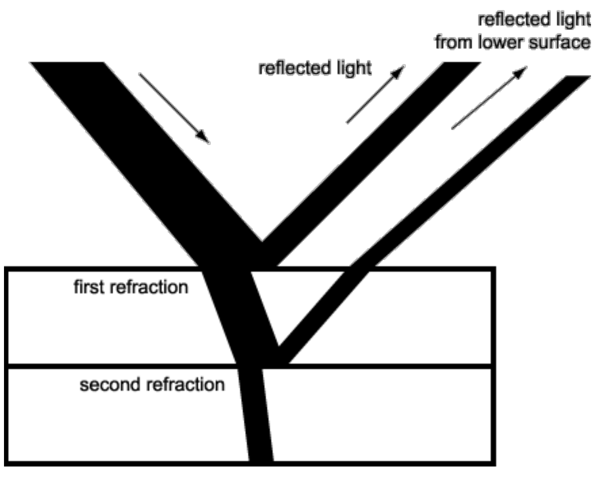

IMAGE 8. ILLUSTRATION OF TWO REFRACTIONS OF ONE LIGHT BEAM

Luc Tuymans (1958), Body, 1990, Oil on Canvas, 48,5 x 38,5 cm, Stedelijk Museum voor Actuele Kunst, Gent.[17]

"It is made with a specific technique, because underneath the layer of paint I used a certain medium that sort of produces craquelé or cracks in the paint prematurely, so that it actually looked aged already when it was made in the nineties. So it was rather on purpose."[18]

The cracks in some paintings by Luc Tuymans are remarkable because of their age. Without context one can question the material consciousness of the artist, as well as the life that the object has had. Luc Tuymans deliberately plays with the idea of time by consciously using the properties of paint and media.

[17] https://smak.be/nl/nieuws/werk-body-van-luc-tuymans-uit-smak-collectie-nu-te-zien-in-venetie

[18] https://www.youtube.com/watch?v=rsD2b4bSdWE

Binders

Now that it has been determined what properties pigments have and what pigments contribute to paint, the same has to be done for the other half of paint, the binder. The chapter has a similar approach. It does not cover the complete realm of binding materials. It covers the essential property of a binder, the formation of the film and examines oil, a classic but still very popular binder. In comparison to a good artist's handbook, that should encompass the entire realm of binders, this structure is incomplete. Nevertheless, the structure will work for a first encounter or introduction with the technicalities of binders and oil. One of the books that makes use of an older structure is *The Materials of the Artist and Their Use in Painting* published in 1921 and written by Max Doerner, a German artist most famous for his book that has long been the technical basis for every painter. It discusses the binders in two subchapters that are appealing to the imagination: non-aqueous techniques and aqueous techniques. A more recent book treats it differently. *Het Kunstschilderdoek* by Kraaijpoel & Herenius, from 2007, divides it into four main groups: physically reversible, physically irreversible, oxidatively drying and chemically drying. The last structure is very relevant and can be of great importance for the advanced painter but can also be confusing for the beginner. Max Doerner’s approach seems more natural but is dated on some fronts. It is certainly advisable for the painter to study both books. This chapter will include aspects of both sources in its concise elaboration.

Film

Where the pigment mainly provides color perception, the binder, in both liquid and dried state, ensures the character of the paint. It determines, for example, the elasticity, durability and the diluent that should be used. Each specific binder has different attributes but they all have at least one property in common; providing a film, a paint film. The film is the essential property of a binder. Without it, a layer of paint would not exist, this immediately sets the first requirement for a binding material.

A film is a coherent membrane that is formed by the binder after drying. How it appears varies per substance. A film can come into existence through oxidation, chemical reaction or by evaporation of a solvent. Chemically drying binders refer to paints that makes use of two components that enter into a chemical reaction: a standard lacquer and a hardener. The lacquer needs a hardener to be able to dry. These paints are not very common in the realm of artist paints but can be functional for murals that have to be wear and impact resistant. The paints are very strong and durable, with the proviso that the correct proportions have been used and the paint has been applied properly.

Much more common artist paints are those that dry oxidatively. Examples of oxidatively drying binders are oils and resins. In these drying processes a chemical reaction takes place as well, but in this case in reaction with ultraviolet light and oxygen. The reaction takes place between the binder molecules, but is fueled by oxygen and light. Oxygen has a temporary role in the polymerization (the merge of molecules) and it creates sustainable connections with the fatty acids, also known as oxidation. Ultra violet light breaks down the degradation products that are not entirely volatile. These products can continue to exist in the dark and function as plasticizers. In this case the film stays sticky. It is conceivable that it is not a desired effect, so it is important that light is allowed to reach the layer of paint in the drying proces.

Binders in which the film appears by evaporation of a solvent are referred to as physical drying binders. Well known examples are gouache and water color paints. Physical reversible binders first have to be dissolved before they can be processed because they appear in solid state. Some are water soluble, others need turpentine or another organic solvent. After the solvent has evaporated, a film appears that is chemically unchanged compared to its previous, solid state. This means that the film layer can be dissolved at all times, and explains the name, reversible. The most common physical reversible binders are Arabic gom, the binder for watercolor paints and dextrin, the binder for gouache.

Physical irreversible binders refer to synthetic resin dispersions. These substances are aqueous dispersions consisting of small resin spheres that are not water-soluble at all. The small spheres cause the film to form after the water, which liquefies the substance and is used to dilute the paint, has evaporated. They flow together into one transparent layer. No chemical change has occurred while transforming to film in this binder either, similar to the reversible binders, but as the name may indicate, the film will never regain its dispersion state. There are certain solvents that can dissolve the binder, but those can only destroy the film: they can not restore the substance to its previous state. The obvious example that makes use of synthetic resin dispersions are acrylic paints.[19]

Oil

Oils that are qualified for the procession of paint are referred to as drying oils. These oils are vegetable oils and contain a high percentage of fat and therefore belong to the category of fatty oils as well. 'Fatty oil' is one of the requirements for a paint oil but does not mean an immediate qualification for the procession of paint. It has to be qualified as a drying oil or half-drying oil first. A drying oil must be specified separately because of its air drying property. This property is due to the percentage of polyunsaturated fatty acids in the oil molecules. A drying oil consists of more than 60 percent out of polyunsaturated fatty acids and is the crucial element where the drying oil sets itself apart from other oils. The polyunsaturated fatty acid ensures a good absorption of oxygen. When the oxygen is absorbed, the fatty acid chains can form compounds. Visually speaking, this means the formation of the film. Oils that do not consist out of polyunsaturated fatty acid, simply do not form a film and therefore cannot be processed in paint. In terms of molecules, a polyunsaturated fatty acid is a triglyceride. This is a molecule that consists of a strain ,glycerol, to which three fatty acids are attached. The fatty acids that are attached have one, two or three spots where the molecules during the drying can link to each other. These spots are called the unsaturated bonds. The more of the unsaturated bonds, the stronger the film and quicker the drying time will be. There is only one oil that consists largely out of triglyceride with three unsaturated compounds and therefore qualifies itself for a drying oil. It is the by far most used oil in painting, linseed oil. The other oils used in paint are half drying oils. Those oils do have some of the required amount of unsaturated bonds and therefore do have a function in painting, but the drying time is longer and the film considerably weaker. Examples of those oils are poppy oil, sunflower oil and safflower oil.

The use of linseed oil in paint ensures a strong film. Oxidation allows the oil to become an elastic, glossy film of linoxyn, a solid. Linoxyn is the exact term to describe oxidized linseed oil. The oil dries in two to four days on a non-absorbent surface. Half-drying oils in six to twelve days, a comparison that confirms the advantage of linseed. Linseed oil is extracted from linseed, which are seeds from the flax plant, the same plant that provides the linen for canvasses. The raw oil must first be cleaned from mucilage after it is extracted. The cleaning is done by three different methods: heating the oil to 300 degrees causing the slime to clump together, addition of small amounts of lye which can be separated from the oil with the mucus, and the addition of infusion-oriented earth (bleaching earth) which absorbs not only the slime substances, but also the dyes present in the oil. After the cleaning, a pure and clean oil remains and is ready to be processed in a paint.[20]

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[19] Het kunstschilderboek, Kraaijpoel & Herenius, p.20-34

[20] Schilderkunst Materiaal en Techniek, Max Doerner, P.81-90

As with many painting materials, either positive or negative, light is a significant factor. Light has, in big contrast with pigments, positive effects on linseed oils that are manufactured for painting. The light bleaches the oil and breaks down degradation products that can function as plasticizers and cause a sticky surface. Therefore an oil painting should never dry in the dark. It will darken the painting and leaves the painting in a sticky state.

Francis Bacon (1909-1992), Study for Portrait, 1977, oil and dry transfer lettering on canvas, 78 x 58 1/8 in. (198.2 x 147.7 cm.) Marlborough International Fine Art, Vaduz[21]

The majority of Francis Bacon's paintings consist of oil paint and pastel on unprepared linen. In combination with the lack of varnish on his paintings, various studies have shown that the restorers will have a complex task in preserving the canvases. Nevertheless there is a windfall. “Bacon himself favored the aesthetic of seeing the paintings behind glass, as it gave them a certain distance from the viewer. Therefore the majority of works are glazed, providing an effective barrier, which is particularly important given the problems with cleaning these works that have been outlined.”[22]

[21] https://www.christies.com/lotfinder/Lot/francis-bacon-1909-1992-study-for-portrait-6141744-details.aspx

[22] https://core.ac.uk/download/pdf/4148915.pdf, p.205

Reflection

It would have been the normal course of affairs to finish a thesis with a conclusion but it can not be stressed enough that this document is perhaps never finished. Additions and modifications will be made on a regular basis to make the document as correct and extensive as possible. The goal would already have been achieved if the reader could orientate themselves a little better regarding the painting materials and are able to get a better understanding of what actually happens in the technical painting process. The ultimate goal would have been achieved if the document triggers the painter to extend it with his or her own material research.

As a painter who writes this introduction for myself and perhaps for others, I can say that the material knowledge that I have gained so far, makes me a lot more comfortable with the paint. The differences in qualities and types of paint can be experienced as very abstract as well as very small. By simply researching the topic, I now understand why I prefer certain materials and that the differences are quite vast. This used to be difficult to put into words and felt as something that was not correct at all. The research has emphasized the fact that paint is not as obvious as it seems. No matter how abstract or vague it sounds, it made me aware that painting is actually much more about the paint than is sometimes discussed. In a conceptual academy, the value that the material has for a work, can be quickly overlooked. Material research can be very useful to reinforce this, and raise awareness for it in terms of discussing a work. Despite not seeing myself as a material painter, I now appreciate the game with paint more and see it as a significant facet in the process of painting.

In addition to these fairly obvious findings, the research has generated questions to which I do not yet have definitive answers or ideas. It made me think about the role of technique in an artist practice and how urgent material knowledge still is. In the introduction of the text, I state that material can have a decisive effect, but of course I do not mean that this should always be the case.

One line of thought I had about material awareness led me to two somewhat opposite tracks that could be further elaborated, may not exclude each other and with which I would like to complete the reflection for now. Coincidences and accidents can be nutritious soil for new promptings, but in order to give these coincidences a well-founded playing field, conscious material-technical decisions may have to be made. In this way coincidences can develop into works that stand firmly on both feet, in which the decision in question has acted as fuel. Decisions can become more conscious and substantiated if there is a better understanding of materials and to complete that circle it can be stated that knowledge is the base of a better understanding. This track seems reasonable but on the other hand, conscious and substantiated decisions are not necessarily desires for every painter. For them, I think material knowledge can also function in an unconscious way. The painter can perhaps move more freely within its medium when material knowledge has become unconscious matter. The knowledge will have a share in the act but will never prevail. In this way the knowledge is not an obstacle to experiments and possible coincidences, but acts as a silent fuel in the act of painting and so I think a possibly feared rigid working method is excluded.

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Appendix

Table 1. Particle sizes, specifically for watercolors. [23]

average pigment particle size		
microns	meters	representative pigments
1000µm	10^{-3}	1 millimeter
500µm		.
100µm	10^{-4}	coarse historical mineral pigments modern luster & iridescent pigments
50µm		smallest particles visible without magnification cobalt violet manganese blue
10µm	10^{-5}	cobalt green cobalt turquoise cerulean blue manganese violet black iron oxides
5µm		ultramarine blue (RS) viridian cobalt blue violet (brown) iron oxides yellow iron oxides
1µm	10^{-6}	ultramarine blue (GS) red iron oxides cadmium red cadmium orange semiopaque synthetic organics diarylides pyrroles naphthols perinone orange
0.5µm		= 500 nanometers = wavelength of "blue green" light chromium oxide green cadmium yellow bismuth yellow titanium white transparent red iron oxides transparent yellow iron oxides semitransparent synthetic organics arylides benzimidazolones dioxazines perylenes
0.1µm	10^{-7}	zinc white iron [prussian] blue transparent synthetic organics quinacridones phthalocyanines
0.05µm		carbon black
0.01µm	10^{-8}	
0.0015µm	10^{-9}	glucose (corn syrup) molecule
0.0003µm	10^{-10}	water molecule

[23] https://www.handprint.com/HP/WCL/pigmt3.html#particlesize

Table 2. Refractive Index Pigments [24]

Color	Pigment	Refractive Index
Blues	Azurite	1.73–1.84
	Indigo (natural dye)	1.49–1.52
	Smalt	1.49–1.52
	Lazurite (natural ultramarine)	1.50
	Vivianite (blue ocher)	1.58–1.70
Greens	Chrysocolla	1.58–1.60
	Dioptase	1.64–1.71
	Glauconite (green earth)	1.62
	Malachite	1.65–1.90
	Verdigris (basic copper acetate)	1.53–1.56
	Volkonskoite	2.50
Yellows	Gamboge (organic resin)	1.58–1.59
	Indian yellow (organic resin)	1.67
	Jarosite	1.71–1.82
	Massicot (litharge, lead monoxide)	2.50–2.61
	Goethite (yellow ocher)	2.00–2.40
	Orpiment	2.40–3.02
Reds	Cinnabar	2.81–3.15
	Hematite (red iron oxide)	2.78–3.01
	Realgar	2.46–2.61
	Red lead (minium or lead tetroxide)	2.42
	Vermilion	2.82–3.15
Browns	Goethite (brown ocher)	2.08–2.40
	Siderite	1.57–1.78
	Sienna, burnt	1.85
	Sienna, raw	1.87–2.17
	Umber, burnt	2.20–2.30
	Umber, raw	1.87–2.17
Whites	Chalk (whiting, calcium carbonate)	1.51–1.65
	Gypsum, anhydrite (calcium sulfate anhydrate)	1.57–1.61
	Gypsum, hemihydrate (gesso, calcium sulfate hemihydrate)	1.52–1.53
	Titanium dioxide (anatase)	2.27
	Titanium dioxide (rutile)	2.71
	Lead white (basic lead carbonate)	1.94–2.09
	Zinc oxide	2.00–2.02

[24] https://www.naturalpigments.com/artist-materials/transparent-opaque-paints/

Table 3. Refractive Index Binders.[25]

Material	Refractive Index
Water	1.333
Linseed oil, refined, fresh*	1.479
Linseed oil, aged 10 years	>1.520
Egg yolk, dried	1.525
Artificial Resins	
Polyvinyl acetate (PVA)	1.473
Acrylic (methyl methacrylate)	1.489–1.498
Acrylic copolymer (methyl methacrylate styrene)	1.558–1.574
Natural Resins	
Damar, Singapore	1.515
Rosin, wood, Grade M	1.525
Rosin, ester	1.496
Shellac, bleached	1.534
Mastic	1.536
Canada balsam	1.530–1.540
Sandarac	1.545

[25] https://www.naturalpigments.com/artist-materials/transparent-opaque-paints/