Relatório Final da Disciplina F 809 – Instrumentação para Ensino
Coordenador: Prof. Dr. José Joaquin Lunazzi

Céu Azul

Dispersão da Luz Solar na Atmosfera e Sensibilidade do Olho Humano a Luz

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Resumo

O projeto teve como objetivo esclarecer que processos ocorrem na natureza e em nosso organismo, para que nós, seres humanos, enxerguemos o céu azul e o crepúsculo alaranjado. Para mostrar o mesmo fenômeno que ocorre na atmosfera terrestre, realizaremos um experimento que mostra como um feixe de luz se comporta quando se desloca em um meio com muitas partículas, como é o caso dos raios do Sol quando entram na atmosfera. Para explicar a parte biológica do fenômeno usaremos pesquisas já realizadas nesta área.

Teoria

O espalhamento da luz por pequenas partículas foi explicado no final do século XIX pelo físico **John William Strutt**, o *Barão de Rayleigh* - ganhador do Prêmio Nobel de Física de 1904, pelos seus estudos de gases e pela descoberta do Argônio [1], no qual, baseado na idéia de que a luz, sendo esta uma onda eletromagnética, ao atingir uma pequena partícula, cria um momento de dipolo induzido. Sabemos que um dipolo elétrico ou magnético oscilante tem o poder de gerar uma radiação eletromagnética, assim, o momento de dipolo criado pela luz na partícula irradia, mas não necessariamente na mesma direção do deslocamento da luz inicial. Esse fenômeno é denominado de espalhamento elástico da luz por partículas, o termo elástico vem do fato de desprezarmos a absorção no fenômeno.

A partir deste conceito, Lord Rayleigh mostrou que a intensidade de luz espalhada é proporcional ao inverso da quarta potência do comprimento de onda [$I(\lambda) \propto 1/\lambda^4$]. A partir da equação de espalhamento de Rayleigh verificamos que comprimento de ondas maiores, como vermelho (~680nm) e o laranja (~ 610nm) possuem uma intensidade de espalhamento menor, para um mesmo caminho percorrido, do que a do azul (~480nm) e a do violeta (~ 420) [6]. Logo, teremos que um feixe de luz branca deslocando em um gás de pequenas moléculas será espalhado de modo que sua porção com menor comprimento de onda será espalhado mais intensamente "antes".

Figura 1 - Lord Rayleigh

Função de Espalhamento, em Termos do Comprimento de Onda, para Pequenas Partículas

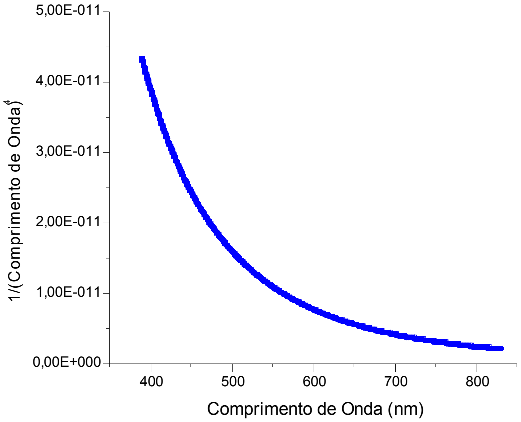


Figura 2

Para saber mais sobre espalhamentos vá a referência [3 e 5].

Devido à densidade, à composição e à espessura da atmosfera terrestre, a luz branca do sol que chaga até nós é espalhada mais intensamente para o azul e o violeta. Mas dissemos que quanto menor o comprimento de onda maior o espalhamento, então porque o céu não é violeta? Já que o espectro do Sol está justamente nos comprimentos de onda da luz visível (figura 3)

Espectro do Sol obtido no laboratório da disciplina F 740

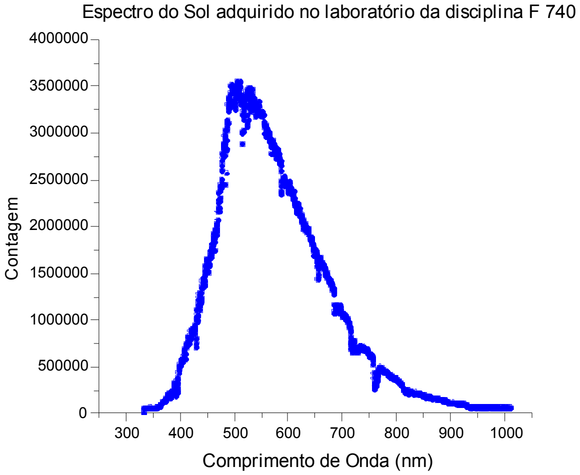


Figura 3

Estas "falhas" no espectro do Sol são explicadas por serem exatamente o comprimento de onda que as partículas do ar absorvem. Pode se ver com mais detalhes na referencia [5]

- **Por que o céu não é violeta, então?**

Na retina do olho dos seres humanos temos dois tipos de células fotossensíveis, os cones e os bastonetes. Os bastonetes são responsáveis para visão quando tem pouca luz no ambiente e diferença os tons de cinza. Já os cones, são responsáveis pela observação das cores e detalhes em ambientes bem iluminados. Há pelo menos três tipos de cones, cada um é mais sensível a uma faixa de comprimento de onda, podendo ser azul, verde ou vermelho.

Imagem Adquirida por Microscopia Eletrônica de Dois Cones entre Muitos Bastonetes

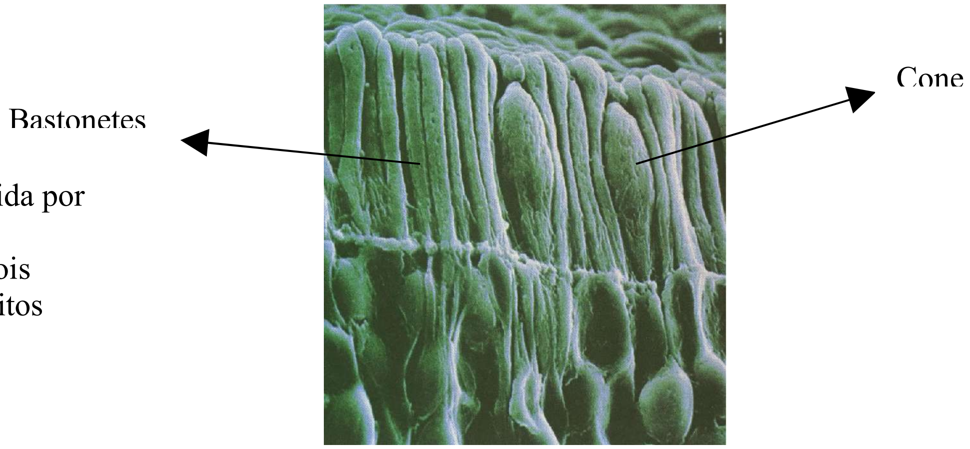
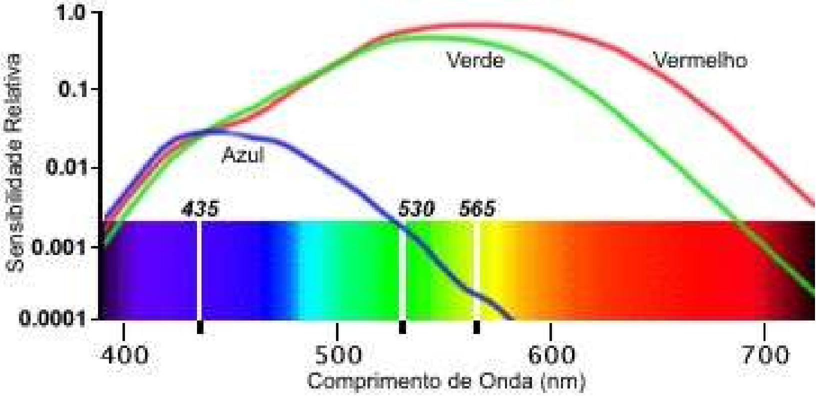


Figura 4

A combinação das informações adquirida por estes três diferentes cones é que gera as cores em nossa visão. Mas a sensibilidade de cada tipo de cone é diferente (figura 5), mesmo para uma mesma intensidade de luz no comprimento de onda em que cada um é mais "sensível". Com essa informação, criou-se uma curva de sensibilidade relativa do olho, que leva em conta a sensibilidade de cada tipo de cone (figura 6).

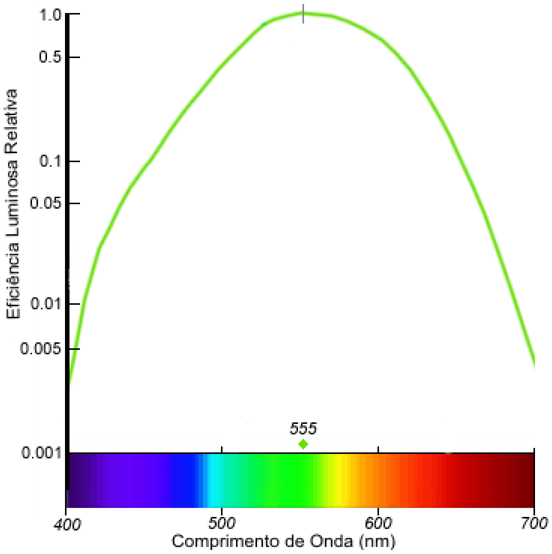


Sensibilidade Relativa de Cada Cone do Olho Humano

Sensibilidade Relativa dos Cones do Olho Humano, em Termos do Comprimento de Onda

Figura 5

Olhando para esta curva, observamos que o comprimento de onda mais sensível ao olho é na faixa do verde (~555nm). Vemos também, que a curva decresce rapidamente e que na região do violeta o olho humano é muito pouco sensível.



Eficiência Luminosa Relativa para os Três Cones, em termos do Comprimento de Onda

Figura 6

Logo, apesar do violeta ter uma intensidade de espalhamento muito grande na atmosfera até chagar a nós, nosso olho é pouco sensível neste comprimento de onda, suficiente para que o azul, mais perceptível ao olho humano, apareça com predominante quando olhamos para o céu.

- **Dipolo**

Um conjunto de duas cargas puntiformes conforme figuras abaixo é dito um dipolo elétrico.

Configuração do Campo Elétrico Gerado por um Dipolo Próximo das Cargas

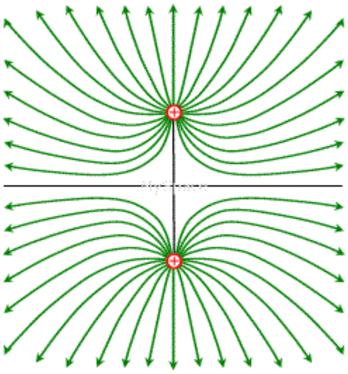


Figura 7

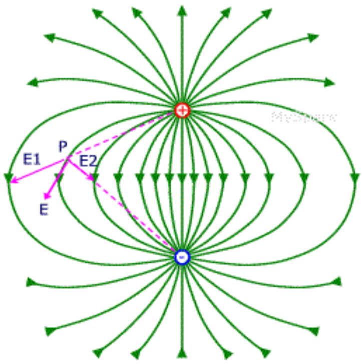


Figura 8

A distância entre as cargas é considerada como um vetor de módulo 2d. O produto deste vetor pelo valor da carga é um outro vetor na mesma direção designado por:

$$\boldsymbol{p} = 2d\,q \qquad (1)$$

Esse vetor é chamado de **momento de dipolo elétrico.**

Campo Elétrico Gerado por um Dipolo Elétrico

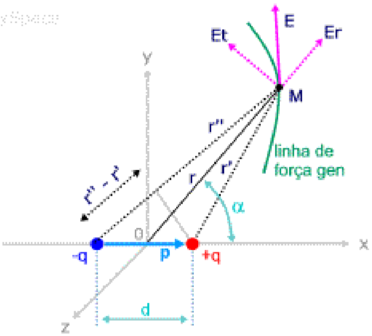


Figura 9

Se o momento elétrico do dipolo é constante, há apenas o campo elétrico. Se ele oscila, o campo varia com o tempo e também há um campo magnético variável conforme leis do eletromagnetismo (figura 10). Isto sugere, e a prática confirma, a irradiação de ondas eletromagnéticas.

Campo Elétrico e Magnético Gerados por um Dipolo Oscilante

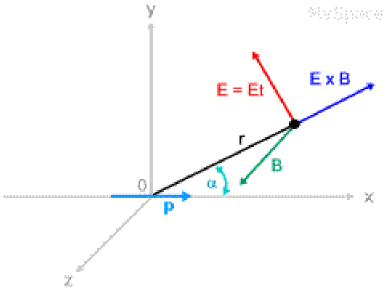


Figura 10

Um dipolo oscilante pode ser formado, por exemplo, pela perturbação do movimento de elétrons num átomo ou por um dispositivo comum, como uma antena para telecomunicação. Considerando o caso prático mais comum, isto é, oscilação senoidal, o momento do dipolo oscilante é dado por:

$$p(t) = p_0 \, sen(wt) \qquad (2)$$

Assim, quando observamos o campo irradiado pelo dipolo oscilante perto dele, veremos uma configuração aproximadamente assim:

Radiação Gerada por um Dipolo Oscilante, Observada Perto do Dipolo

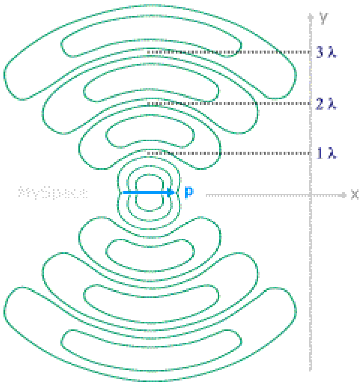


Figura 11

- **Polarização da Luz do Sol**

A luz espalhada pela atmosfera é resultante da criação de um dipolo na nuvem eletrônica das moléculas do ar pela luz do Sol. O dipolo oscilante irradia. A radiação criada é a luz espalhada. Mas como vemos na figura anterior, um dipolo oscilante irradia muito mais intensamente na direção do plano perpendicular à direção do vetor momento, no seu "equador". Assim, para uma pessoa que observa o céu de costas para Sol, a luz que chega até ele pelos lados é polarizada verticalmente, enquanto que a luz que vem da sua frente é polarizada horizontalmente, assim como o observado na experiência (figura 13).

Logo, o espalhamento da luz do Sol pela atmosfera é responsável pela polarização da luz do Sol.

Experimento

O experimento escolhido consiste na simulação do espalhamento Rayleigh, que ocorre na atmosfera terrestre, dentro em um aquário com água. Pare simular os raios solares utilizamos um feixe de luz branca. A luz branca quando passa pelo aquário é espalhada pelas partículas suspensas na água, assim, como o azul tem uma intensidade de espalhamento maior do que o vermelho, deveríamos ver o feixe azulado, quando olhamos pela lateral do aquário. Logo, deveríamos ver também, o feixe de luz avermelhado no lado oposto a fonte de luz, no aquário (figura 12).

Esboço que
Esquematiza o
Experimento
Realizado

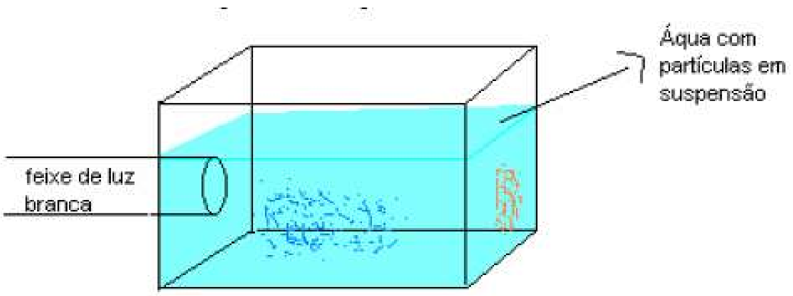


Figura 12

Baseado nos sítios de referência [9-10], inicialmente realizamos a nossa experiência utilizando 250ml de leite e um aquário de 20 litros, com 15 litros de água.

Com uma fonte de luz branca de 4V e uma lente na frente da fonte, para que o feixe se desloca mais paralelamente, ou seja, com foco no infinito. Observamos que a água do aquário, a partir dos 5mL, ficou muito turva, não era possível nem observar o feixe de luz na lateral do aquário, nem a luz vermelha que deveria chagar do outro lado do aquário.

Então resolvemos diminuir a concentração, para menos de 2mL, ver referência [11], no aquário com 15 litros de água. Com essa montagem, observamos que o de luz transmitido na água do aquário era perceptível, nitidamente víamos um feixe de luz. Apesar do feixe de luz se tornar avermelhado no lado oposto à fonte de luz, o feixe visto pela lateral do aquário era muito pouco azul, quase imperceptível.

Como estamos montando um experimento didático, ele deve ser bem claro e o fenômeno deve ser muito nítido. Pensando assim, decidimos aumentar a intensidade da fonte, pois assim teríamos mais luz espalhada, e diminuir a largura do aquário, porque sendo este relativamente largo, o azul poderia não chegar na borda, pois é facilmente espalhada.

Com essa nova configuração, observamos que luz espalhada ficava um pouco mais azul, mais ainda era insuficiente nítida a sua coloração azul.

Em busca de alternativas, fizemos o experimento baseado na referência [13], que utilizava leite em pó, mais o experimento também não deu muito certo, pois o leite em pó dilui com uma grande dificuldade em água fria, assim as partículas em suspensão eram muito grandes, e assim, o espalhamento ficava muito pouco nítido.

A partir daí, fomos em busca de mais referência que tratavam sobre o assunto. Então encontramos, um método para realizarmos o experimento, de modo que ficasse o espalhamento ficasse claro e nítido dentro do aquário.

Achamos dois experimentos na internet, na qual, o espalhamento não é devido ao número fixo de moléculas suspensas na água, ou seja, ao número fixo de moléculas que não são solúveis na água, como é o caso do leite e do café [12]. Neste dois sítios [14-15], os autores utilizam uma reação química na água do aquário, para gerar moléculas não solúveis na água progressivamente. A vantagem desse método vem do fato das moléculas insolúveis na água se formaram com o passar do tempo, assim, o que vemos no aquário é uma mudança progressiva da cor do feixe visto na lateral do aquário, que vai do branco, quando temos poucas partículas insolúveis, para o azul e depois, para o amarelo, para o laranja e vermelho, de maneira muito nítida.

A variação progressiva ocorre também na cor da luz que deixa o aquário, do lado oposto ao da entrada do feixe de luz. Se colocarmos um anteparo, vemos o feixe passando do branco, para o amarelo, laranja e um vermelho bem intenso.

Equação da Reação
Química e a
Solubilidade em
Água dos produtos

$$H_2SO_4 + Na_2S_2O_3 \xrightarrow{H_2o} \overset{\overset{\text{insolúvel}}{\nearrow}}{S^{-2}} + 2\underset{\underset{\text{solúvel}}{\searrow}}{Na^{+1}} + \overset{\overset{\text{solúvel}}{\nearrow}}{O_2} + \underset{\underset{\text{solúvel}}{\searrow}}{SO_4^{-2}} + H_2O \qquad (3)$$

Logo, o maior responsável pelo espalhamento no experimento é o íon S^{-2}.

- **Polarização da Luz Espalhada no Experimento**

A polarização da luz espalhada deve-se ao modo no qual os dipolos oscilantes irradiam, com visto anteriormente.

Assim como a luz do Sol, que pode ser vista polarizada, dependendo do referencial e da direção que um observador está olhando, a luz espalhada pelas moléculas suspensas na água também pode ser vista polarizada. Podemos confirmar essa afirmação utilizando um filtro polarizador e com este, observar a luz espalhada pela atmosfera e pelas moléculas na água do aquário.

A diferença entre os dois fenômenos é o referencial de observação. Quando observamos a luz do Sol espalhada, esta está toda ao nosso redor, enquanto que a luz espalhada dentro do aquário é vista em um referencial fora do aquário.

Entretanto, há semelhanças de polarização da luz espalhada. Quando olhamos para o céu, de costas para o Sol, utilizando um filtro polarizador, vemos que a luz vinda de cima é polarizada horizontalmente, a luz vinda dos lados é polarizada verticalmente e a luz vinda das costas e da frente não são polarizadas. No experimento, quando observamos a luz espalhada por cima do aquário, esta é vista polarizada horizontalmente, quando vista pelos lados do aquário, ela é polarizada verticalmente e não há polarização quando observamos a luz vinda da entrada do feixe e da saída do feixe (figura 13).

Esboço da
Polarização da Luz
Espalhada no
Experimento

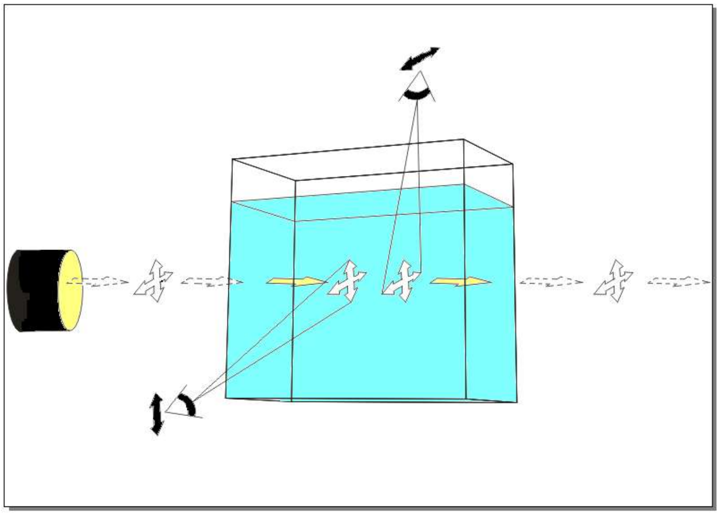


Figura 13

- **Fotos do Experimento**

Foto da Montagem
Experimental -
Antes da Reação
Química Começar.

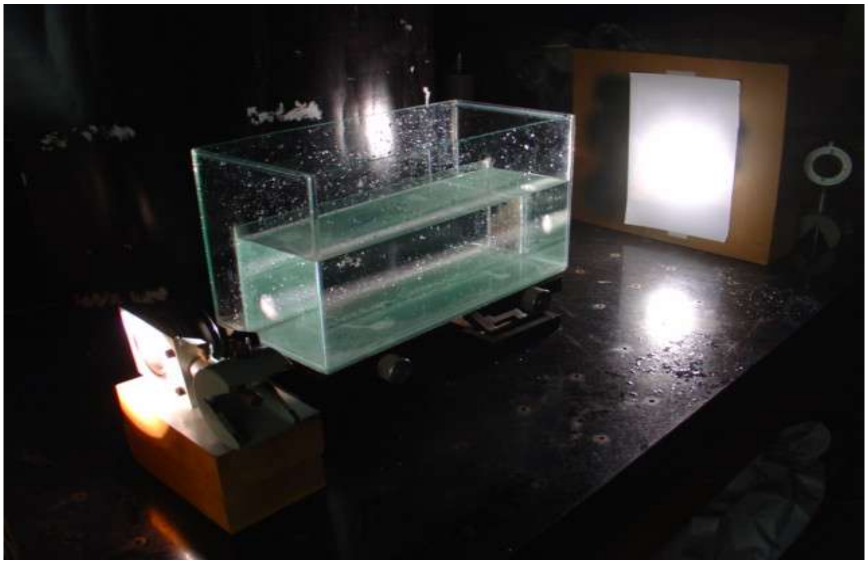


Figura 14

Apresentação do Experimento – Onde é Possível Observar a Coloração Amarelo-Alaranjada da Luz que Chega ao Anteparo

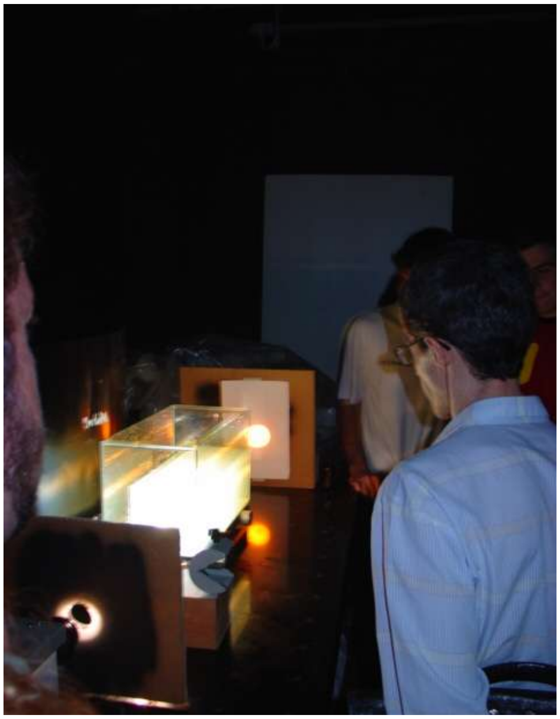


Figura 15

Apresentação do Experimento – No Qual o Feixe de Luz que Chega ao Anteparo é Vermelho.

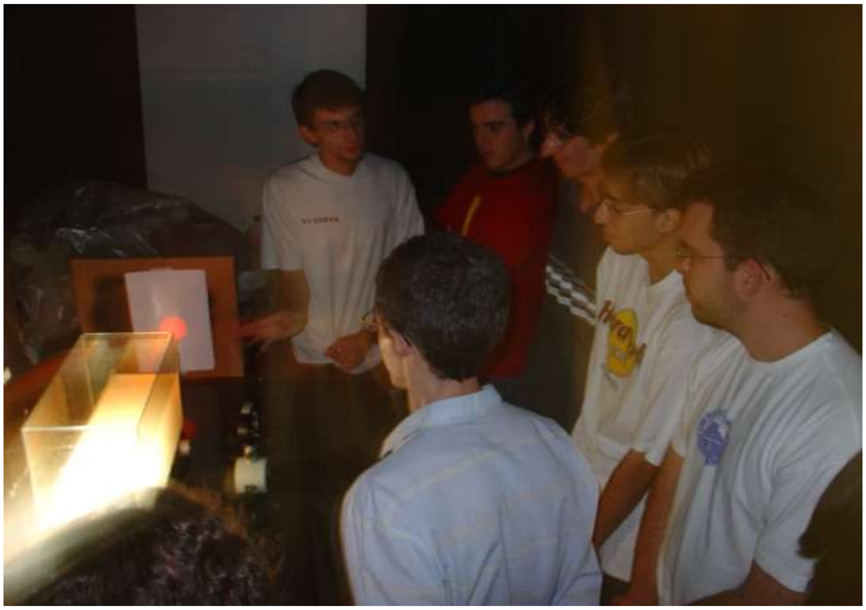


Figura 16

Apresentação do Experimento – Agora a Água está Turva Demais para que Chegue Luz ao Anteparo.

Figura 17

<u>A demonstração foi filmada pelo coordenador e o vídeo consta do acervo da disciplina.</u>

Conclusão

O experimento realizado, se feito com atenção e segurança, é um experimento simples e fácil, mas isso não o torna menos intrigante. Ele é um experimento muito bonito visualmente e abre espaço para muitas explicações físicas, alem das biológicas e químicas.

A partir de um único experimento foi possível explicar um dos tipos de espalhamento da luz, a polarização da luz espalhada, conseqüentemente da luz do Sol que chega até nós, o conceito de dipolo e momento de dipolo, alem da radiação gerada por um dipolo oscilante, a maneira na qual o olho humano compõe as cores que enxerga, de um modo muito simplificado, alem do conceito de solubilidade.

O mais interessante de tudo é que o experimento auxilia na explicação do porque do céu ser azul, uma questão que a maioria de nós já se fez e que aqui está explica de uma maneira simples e fácil.

Comentários do Coordenador

- As abelhas, baseadas na polarização da luz do Sol, são capazes de orientar-se e guiar as outras abelhas da mesma colméia para uma posição exata.
- Foi observado na gravação do vídeo que a polarização da luz espalhada quando a água já estava turva não é tão nítida quanto à polarização da luz espalhada antes da reação

química iniciar. Provavelmente pelo fato de haver espalhamentos secundários na primeira situação.

- Os motivos pelos quais as ondas que possuem comprimentos de onda menores, como azul e violeta, serem mais intensamente espalhados e refratados, são pouco explorados no curso de graduação e nos livros que tratam do assunto.
- O relatório parcial, que foi entregue anteriormente a este, se encontra pobre na parte teórica.

As figuras 14 a 17 foram cordialmente cedidas pelo Eng. Antonio Carlos da Costa.

Referências

[1] http://nobelprize.org/physics/laureates/1904/strutt-bio.html

Lord Rayleigh – Biography

John William Strutt, third Baron Rayleigh, was born on November 12, 1842 at Langford Grove, Maldon, Essex, as the son of John James Strutt, second Baron, and his wife Clara Elizabeth La Touche, eldest daughter of Captain Richard Vicars, R. E. He was one of the very few members of higher nobility who won fame as an outstanding scientist.

Throughout his infancy and youth he was of frail physique; his education was repeatedly interrupted by ill-health, and his prospects of attaining maturity appeared precarious. After a short spell at Eton at the age of 10, mainly spent in the school sanatorium, three years in a private school at Wimbledon, and another short stay at Harrow, he finally spent four years with the Rev. George Townsend Warner (1857) who took pupils at Torquay.

In 1861 he entered Trinity College, Cambridge, where he commenced reading mathematics, not at first equal in attainments to the best of his contemporaries, but his exceptional abilities soon enabled him to overtake his competitors. He graduated in the Mathematical Tripos in 1865 as Senior Wrangler and Smith's Prizeman. In 1866 he obtained a fellowship at Trinity which he held until 1871, the year of his marriage.

A severe attack of rheumatic fever in 1872 made him spend the winter in Egypt and Greece. Shortly after his return his father died (1873) and he succeeded to the barony, taking up residence in the family seat, Terling Place, at Witham, Essex. He now found himself compelled to devote part of his time to the management of his estates (7000 acres). The combination of general scientific knowledge and acumen with acquired knowledge of agriculture made his practice in estate management in many respects in advance of his time. Nevertheless, in 1876 he left the entire management of the land to his younger brother.

From then on, he could devote his full time to science again. In 1879 he was appointed to follow James Clerk Maxwell as Professor of Experimental Physics and Head of the Cavendish Laboratory at Cambridge. In 1884 he left Cambridge to continue his experimental work at his country seat at Terling, Essex, and from 1887 to 1905 he was Professor of Natural Philosophy in the Royal Institution of Great Britain, being successor of Tyndall.

He served for six years as President of a Government Committee on Explosives, and from 1896 to 1919 he was Scientific Advisor to Trinity House. He was Lord Lieutenant of Essex from 1892 to 1901.

Lord Rayleigh's first researches were mainly mathematical, concerning optics and vibrating systems, but his later work ranged over almost the whole field of physics, covering sound, wave theory, colour vision, electrodynamics, electromagnetism, light scattering, flow of liquids, hydrodynamics, density of gases, viscosity, capillarity, elasticity, and photography. His patient and delicate experiments led to the establishment of the standards of resistance, current, and electromotive force; and his later work was concentrated on electric and magnetic problems. Lord Rayleigh was an excellent instructor and, under his active supervision, a system of practical instruction in experimental physics was devised at Cambridge, developing from a class of five or six students to an advanced school of some seventy experimental physicists. His *Theory of Sound* was published in two volumes during 1877-1878, and his other extensive studies are reported in his *Scientific Papers* - six volumes issued during 1889-1920. He has also contributed to the *Encyclopaedia Britannica.*

He had a fine sense of literary style; every paper he wrote, even on the most abstruse subject, is a model of clearness and simplicity of diction. The 446 papers reprinted in his collected works clearly show his capacity for understanding everything just a little more deeply than anyone else. Although a member of the House of Lords, he intervened in debate only on rare occasions, never allowing politics to interfere with science. His recreations were travel, tennis, photography and music.

Lord Rayleigh, a former Chancellor of Cambridge University, was a Justice of the Peace and the recipient of honorary science and law degrees. He was a Fellow of the Royal Society (1873) and served as Secretary from 1885 to 1896, and as President from 1905 to 1908. He was an original recipient of the Order of Merit (1902), and in 1905 he was made a Privy Councillor. He was awarded the Copley, Royal, and Rumford Medals of the Royal Society, and the Nobel Prize for 1904.

In 1871 he married Evelyn, sister of the future prime minister, the Earl of Balfour, and daughter of James Maitland Balfour and his wife Blanche, the daughter of the second Marquis of Salisbury. They had three sons, the eldest of whom was to become Professor of Physics at Imperial College of Science and Technology, London.

Lord Rayleigh died on June 30, 1919, at Witham, Essex.

From *Nobel Lectures, Physics 1901-1921*, Elsevier Publishing Company, Amsterdam, 1967

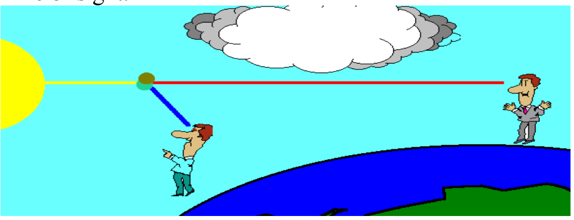
This autobiography/biography was written at the time of the award and later published in the book series *Les Prix Nobel*/*Nobel Lectures*. The information is sometimes updated with an addendum submitted by the Laureate. To cite this document, always state the source as shown above.

[2] http://math.ucr.edu/home/baez/physics/General/BlueSky/blue_sky.html

Original by Philip Gibbs May 1997.

Why is the sky blue?

A clear cloudless day-time sky is blue because molecules in the air scatter blue light from the sun more than they scatter red light. When we look towards the sun at sunset, we see red and orange colours because the blue light has been scattered out and away from the line of sight.



The white light from the sun is a mixture of all colours of the rainbow. This was demonstrated by Isaac Newton, who used a prism to separate the different colours and so form a spectrum. The colours of light are distinguished by their different wavelengths. The visible part of the spectrum ranges from red light with a wavelength of about 720 nm, to violet with a wavelength of about 380 nm, with orange, yellow, green, blue and indigo between. The three different types of colour receptors in the retina of the human eye respond most strongly to red, green and blue wavelengths, giving us our colour vision.

Tyndall Effect

The first steps towards correctly explaining the colour of the sky were taken by John Tyndall in 1859. He discovered that when light passes through a clear fluid holding small particles in suspension, the shorter blue wavelengths are scattered more strongly than the red. This can be demonstrated by shining a beam of white light through a tank of water with a little milk or soap mixed in. From the side, the beam can be seen by the blue light it scatters; but the light seen directly from the end is reddened after it has passed through the tank. The scattered light can also be shown to be polarised using a filter of polarised light, just as the sky appears a deeper blue through polaroid sun glasses.

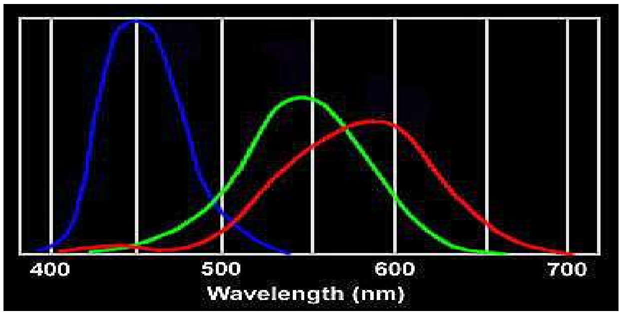
This is most correctly called the Tyndall effect, but it is more commonly known to physicists as Rayleigh scattering--after Lord Rayleigh, who studied it in more detail a few years later. He showed that the amount of light scattered is inversely proportional to the fourth power of wavelength for sufficiently small particles. It follows that blue light is scattered more than red light by a factor of $(700/400)^4 \sim= 10$.

Dust or Molecules?

Tyndall and Rayleigh thought that the blue colour of the sky must be due to small particles of dust and droplets of water vapour in the atmosphere. Even today, people sometimes incorrectly say that this is the case. Later scientists realised that if this were true, there would be more variation of sky colour with humidity or haze conditions than was actually observed, so they supposed correctly that the molecules of oxygen and nitrogen in the air are sufficient to account for the scattering. The case was finally settled by Einstein in 1911, who calculated the detailed formula for the scattering of light from molecules; and this was found to be in agreement with experiment. He was even able to use the calculation as a further verification of Avogadro's number when compared with observation. The molecules are able to scatter light because the electromagnetic field of the light waves induces electric dipole moments in the molecules.

Why not violet?

If shorter wavelengths are scattered most strongly, then there is a puzzle as to why the sky does not appear violet, the colour with the shortest visible wavelength. The spectrum of light emission from the sun is not constant at all wavelengths, and additionally is absorbed by the high atmosphere, so there is less violet in the light. Our eyes are also less sensitive to violet. That's part of the answer; yet a rainbow shows that there remains a significant amount of visible light coloured indigo and violet beyond the blue. The rest of the answer to this puzzle lies in the way our vision works. We have three types of colour receptors, or cones, in our retina. They are called red, blue and green because they respond most strongly to light at those wavelengths. As they are stimulated in different proportions, our visual system constructs the colours we see.



Response curves for the three types of cone in the human eye

When we look up at the sky, the red cones respond to the small amount of scattered red light, but also less strongly to orange and yellow wavelengths. The green cones respond to yellow and the more strongly-scattered green and green-blue wavelengths. The blue cones are stimulated by colours near blue wavelengths which are very strongly scattered. If there were no indigo and violet in the spectrum, the sky would appear blue with a slight green tinge. However, the most strongly scattered indigo and violet wavelengths stimulate the red cones slightly as well as the blue, which is why these colours appear blue with an added red tinge. The net effect is that the red and green cones are stimulated about equally by the light from the sky, while the blue is stimulated more strongly. This combination accounts for the pale sky blue colour. It may not be a coincidence that our vision is adjusted to see the sky as a pure hue. We have evolved to fit in with our environment; and the ability to separate natural colours most clearly is probably a survival advantage.

A multi-coloured sunset over the Firth of Forth in Scotland.

Sunsets

When the air is clear the sunset will appear yellow, because the light from the sun has passed a long distance through air and some of the blue light has been scattered away. If the air is polluted with small particles, natural or otherwise, the sunset will be more red. Sunsets over the sea may also be orange, due to salt particles in the air, which are effective Tyndall scatterers. The sky around the sun is seen reddened, as well as the light coming directly from the sun. This is because all light is scattered relatively well through small angles--but blue light is then more likely to be scattered twice or more over the greater distances, leaving the yellow, red and orange colours.

A blue haze over the mountains of Les Vosges in France.

Blue Haze and Blue Moon

Clouds and dust haze appear white because they consist of particles larger than the wavelengths of light, which scatter all wavelengths equally (Mie scattering). But sometimes there might be other particles in the air that are much smaller. Some mountainous regions are famous for their blue haze. Aerosols of terpenes from the vegetation react with ozone in the atmosphere to form small particles about 200 nm across, and these particles scatter the blue light. A forest fire or volcanic eruption may occasionally fill the atmosphere with fine particles of 500-800 nm across, being the right size to scatter red light. This gives the opposite to the usual Tyndall effect, and may cause the moon to have a blue tinge since the red light has been scattered out. This is a very rare phenomenon--occurring literally once in a blue moon.

Opalescence

The Tyndall effect is responsible for some other blue coloration's in nature: such as blue eyes, the opalescence of some gem stones, and the colour in the blue jay's wing. The colours can vary according to the size of the scattering particles. When a fluid is near its critical temperature and pressure, tiny density fluctuations are responsible for a blue coloration known as critical opalescence. People have also copied these natural effects by making ornamental glasses impregnated with particles, to give the glass a blue sheen. But not all blue colouring in nature is caused by scattering. Light under the sea is blue because water absorbs longer wavelength of light through distances over about 20 metres. When viewed from the beach, the sea is also blue because it reflects the sky, of course. Some birds and butterflies get their blue colorations by diffraction effects.

Why is the Mars sky red?

Images sent back from the Viking Mars landers in 1977 and from Pathfinder in 1997 showed a red sky seen from the Martian surface. This was due to red iron-rich dusts thrown up in the dust storms occurring from time to time on Mars. The colour of the Mars sky will change according to weather conditions. It should be blue when there have been no recent storms, but it will be darker than the earth's daytime sky because of Mars' thinner atmosphere.

[3] Hulst, H. C. van de; Light scattering by small particles, New York: Dover, 1981.

[4] http://ceos.cnes.fr:8100/cdrom-98/ceos1/science/dg/dg15.htm

2.10 Atmospheric scattering

Much of the visible radiation which reaches our eyes is scattered rather than direct. For example light from the sky or from clouds is scattered sunlight. Scattering is a fundamentally significant process in which incident electromagnetic radiation may be affected by the presence of a particle upon which it is incident (see Paltridge and Platt 1976). The particle effectively removes energy from the incoming radiation and reradiates that energy in all directions. Particles in the atmosphere which are important in scattering include:

- gas molecules (size about 10^-8 cm)
- solid aerosols (sizes 0.1 to 1.0 micron)
- cloud water droplets (1 to 10 micron)
- cloud ice crystals (1 to 100 micron)
- hail (up to 10 cm).

The directional dependence of the scattering depends very strongly on the ratio of the scattering particle size to the wavelength of the incoming radiation. Isotropic scattering is characterised by a scattering pattern which is symmetrical about the direction of the incoming radiation. A very small particle tends to scatter light equally in the forward and backward directions relative to the direction of incoming radiation. Larger particles tend to concentrate most of the scattered radiation in the forward direction. There are two basic types of scattering as discussed below.

Firstly when the scattering particles are much smaller than the wavelength of the incoming radiation, Rayleigh scattering takes place. In this case the intensity of light (for example visible or infrared radiation) scattered in a particular direction by air molecules is inversely proportional to the fourth power of the wavelength of incident radiation. For example, Rayleigh theory explains the scattering of sunlight (eg visible and IR wavelengths) by air molecules. Much of the incoming solar radiation is at visible wavelengths. The amount of scattering of sunlight at dark blue wavelengths (about 0.47 micron) is greater than for red light (about 0.64 micron) by a factor of (0.64/0.47)4 = 3.4. Therefore when looking away from the sun the sky appears blue because of the greater Rayleigh scattering at short visible wavelengths. Similarly when the path length for incoming solar radiation is large, as occurs at sunrise or sunset, longer wavelength radiation, which is not scattered so much, is predominant. Hence the red appearance of sunsets/sunrises and the redder apparent colour of the sun at these times. Rayleigh scattering theory also applies to the scattering of microwave radiation by raindrops. The theory is therefore important in understanding and interpreting weather radar observations.

Secondly, when scattering takes places with particles which are comparable to or larger than the wavelength, it is referred to as Mie scattering (see Liou 1980, pp 122-139 or Paltridge and Platt 1976, pp 77-82). To understand Mie scattering theory it is useful to introduce a simplified concept of a scattering area coefficient K which depends on

- a dimensionless size $\propto = 2\ \pi r/\lambda$ parameter which relates particle size to wavelength of radiation ; and
- the refractive index of the medium comprising the scattering particles.

Consider a parallel beam of radiation which is depleted by a fractional amount when passing through a dI_λ/I_λ layer of scattering medium of thickness dz. If A is the effective cross-sectional area of the scattering particles which is presented to the incoming radiation and is the zenith angle, then Asec /dz is the fractional area occupied by the scattering particles as seen by the incoming beam of radiation. Specifically

$$dI_\lambda/I_\lambda = K A \sec \phi / dz$$

Note that K is a function of . $\propto = 2\ \pi r/\lambda$ The range of the size parameter corresponding to various scattering theories is shown in Table 8 below.

Table 8: Scattering

$\propto$	Scattering
$\propto > 50$	Describe angular distribution of scattered radiation by geometric optics i.e. non-selective scattering
$0.1 < \propto < 50$	Mie regime
$0.001 < \propto < 0.1$	Rayleigh scattering
$\propto < 0.001$	Negligible scattering

Figure 18 below shows for various values of scattering particle size r and wavelength .

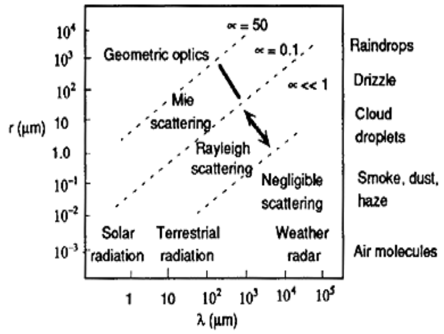


Figure 18: Scattering regimes for various ranges of the size parameter . Ordinate is scattering particle radius r in microns and the abscissa is the wavelength of incident radiation in microns. Adapted from Wallace and Hobbs (1977), p307.

Figure 19 shows K as a function of the size parameter for a refractive index of 1.33. The oscillatory behaviour of K is typical.

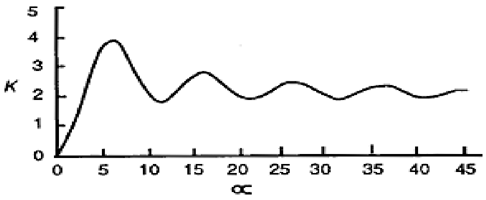


Figure 19: The scattering area coefficient K as a function of the size parameter for a refractive index of the scattering medium of 1.33. Adapted from Wallace and Hobbs (1977), p307.

An example of non-selective scattering is scattering of sunlight by atmospheric constituents such as large aerosols, cloud droplets or ice crystals. In this case the scattering is not very dependent on wavelength which results in the white or grey appearance of clouds. Note that K is a measure of scattering efficiency, and that from the above figure for r >= 0.3 (lambda) then the value of K is fairly constant and largely independent of wavelength. The fact that K tends to a value of 2 indicates that the effective scattering cross section is twice the geometrical cross section, primarily because of diffraction. So for clouds in which the average droplet size is greater than about 4 microns, and with incoming radiation of wavelength less than 2 microns, an assumption is often made in which the geometric cross section is doubled. This is the "large drop" approximation, and is often used in parameterising the interaction of solar radiation with clouds.

Note that although scattering of visible radiation in the atmosphere can be significant, scattering of terrestrial (long wave) radiation with wavelength > 4 microns, is of secondary importance compared to absorption and emission. Table 9 summarises the main types of atmospheric scattering in order of importance.

Theory	Particle size	Type of particle	Comment
Rayleigh	λ < 0.1	Gas molecules	Scattering inversely proportional to fourth power of wavelength. Result: blue sky, red sunset/ sunrise; haze in photography.
Mie	>= λ	Small cloud droplets, dust, fumes etc	Generalised theory. Affects long visible wavelengths.
Non-selective	>> λ	Cloud droplets, dust etc	Applies to scattering by fog and clouds. Scattering is largely independent of λ . Results in whitish colour of fog, clouds.
Raman	any size	any particle	Elastic collision of photon with molecule. Results in change of wavelength of incoming radiation.

Table 9: Main atmospheric scattering processes*

* based on Curran (1985), p.54

Dr D C Griersmith

[5] http://ls7pm3.gsfc.nasa.gov/whatsRM/whathappens.html

What Happens to the Radiation Hitting the Earth?

Three things can happen to radiation when it meets an object (atmosphere, pig, cow, tree, water, etc.). It can be absorbed, scattered, or transmitted.

Absorption
Mostly caused by three atmospheric gasses;

1. Ozone - absorbs UV
2. Carbon Dioxide - Lower atmosphere; absorbs energy in the 13 - 17.5 mm region.
3. Water Vapor - Lower atmosphere. Mostly important in humid areas, very effective at absorbing in portions of the spectrum between 5.5 and 7 mm and above 27 mm.

Scattering Scattering is the redirection of electromagnetic energy by particles suspended in the atmosphere, or by large molecules of atmospheric gasses. There are 3 main types of scattering:

RAYLEIGH - Upper atmosphere scattering, sometimes called clear atmosphere scattering. It is wavelength dependent and increases as the wavelength becomes shorter. Rayleigh scattering occurs when the atmospheric particles have a diameter smaller than the incident wavelength. It is dominant at elevations of 9 to 10 km above the surface. Blue light is scattered about four times as much as red light and UV light about 16 times as red light. **RAYLEIGH SCATTERING IS WHY THE SKY IS BLUE.** If your kid ever asks why the sky is blue, tell them 'Because the atmospheric particles are about the size of the blue wavelength, a large amount of Rayleigh scattering is occurring in that portion of the EM spectrum in the upper atmosphere.' Guaranteed they will never ask another question.

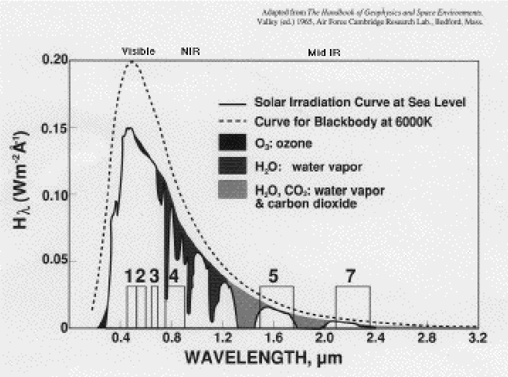
MIE - Lower atmosphere scattering (0-5km). Caused by dust, pollen, smoke and water droplets. Particles have a diameter roughly equal to the incident wavelength, effects are wavelength dependent and affect EM radiation mostly in the visible portion.

NON-SELECTIVE - Lower atmosphere. Particles much larger than incident radiation and scattering is not wavelength dependent. Primary cause of haze.

- General effects of scattering:
    - -Causes skylight (allows us to see in shadow)
    - -Forces image to record the brightness of the atmosphere in addition to the target.
    - -Directs reflected light away from the sensor aperture and
    - -Directs light normally outside the sensor's field of view toward the sensors aperture decreasing the spatial detail (fuzzy images)
    - -Tends to make dark objects lighter and light objects darker (reduces contrast)

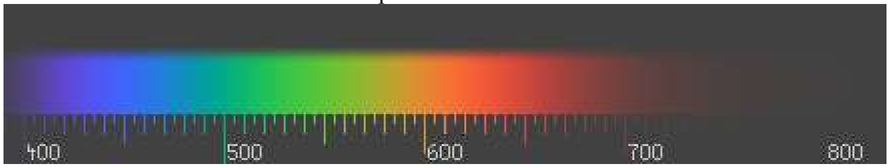
Transmission
Transmission is the movement of light through a surface and is wavelength dependent.
Transmittance is measured as the ratio of transmitted radiation to the incident radiation. Plant leaves can transmit significant amounts of infrared radiation, but cannot transmit visible light as strongly.

Portions of the EM spectrum can pass through the atmosphere with little or no attenuation. These are known as atmospheric windows. The figure below shows these windows (peaks) and areas that are attenuated (valleys).



[6] http://pt.wikipedia.org/wiki/Cor

Cores do espectro visível.

cor	comprimento de onda	freqüência
vermelho	~ 625-740 nm	~ 480-405 THz
laranja	~ 590-625 nm	~ 510-480 THz
amarelo	~ 565-590 nm	~ 530-510 THz
verde	~ 500-565 nm	~ 600-530 THz
ciano	~ 485-500 nm	~ 620-600 THz
azul	~ 440-485 nm	~ 680-620 THz
violeta	~ 380-440 nm	~ 790-680 THz
Espectro Contínuo  *Feito para monitores na gamma 1.5.*		

Cor, freqüência e energia da luz.

Color	λ /nm	ν /10^{14} Hz	ν_b /10^4 cm^{-1}	E /eV	E /kJ mol^{-1}
Infravermelho	>1000	<3.00	<1.00	<1.24	<120
Vermelho	700	4.28	1.43	1.77	171
Laranja	620	4.84	1.61	2.00	193
Amarelo	580	5.17	1.72	2.14	206
Verde	530	5.66	1.89	2.34	226
Azul	470	6.38	2.13	2.64	254
Violeta	420	7.14	2.38	2.95	285
Ultravioleta próximo	300	10.0	3.33	4.15	400
Ultravioleta distante	<200	>15.0	>5.00	>6.20	>598

Cor é um aspecto físico da natureza. A cor de um material é determinada pelos comprimentos de onda dos raios luminosos que as suas moléculas constituintes refletem. Um objeto terá determinada cor se não absorver justamente os raios correspondentes à freqüência daquela cor.

Assim, um objeto é vermelho se absorve todos os raios de luz, **exceto** o vermelho.

A cor é relacionada com os diferentes comprimento de onda do espectro eletromagnético. São percebidas pelas pessoas na faixa da zona visível e por alguns animais através dos órgaos de visão, como uma sensação que nos permite diferenciar os objetos do espaço com maior precisão.

Considerando as cores como luz, a cor branca resulta da superposição de todas as cores, enquanto o preto é a ausência de luz. Uma luz branca pode ser decomposta em todas as cores (o espectro) por meio de um prisma. Na natureza, esta decomposição origina um arco-íris.

Teoria da Cor

Quando se fala de cor, há que distinguir entre a cor obtida aditivamente (cor luz) ou a cor obtida subtractivamente (cor pigmento).

No primeiro caso, chamado de sistema RGB, temos os objectos que emitem luz (monitores, tv, Sol, etc.) em que a adição de diferentes comprimentos de onda das cores primárias de luz Vermelho + Azul + Verde = Branco.

No segundo sistema (subtractivo ou cor pigmento) iremos manchar uma superfície sem pigmentação(branca) misturando-lhe as cores secundárias da luz (também chamadas de primárias em artes plásticas); Ciano + Magenta + Amarelo = preto. Este sistema coresponde ao "CMYK" das impressoras e serve para obter cor com pigmentos (tintas e objectos não emissores de luz).

Muitas vezes o amarelo, azul e vermelho são chamados de primários, o que é incorrecto em ambos espaços de cor. Assim o que se chama **azul primário** corresponde ao ciano. O **vermelho primário** ao magenta e o **amarelo Primário** ao próprio amarelo. O uso de cores diferentes (azul , amarelo, vermelho) neste espaço de cor leva a que não seja possível fabricar todas as cores, e que no circulo das cores certos opostos estejam trocados.

Note-se ainda que antes da invenção do prisma e da divisão do espectro da luz branca, nada disto era conhecido, pelo que ainda hoje é ensinado nas nossas escolas que Amarelo/Azul/Vermelho são as cores primárias das quais todas as outras são passíveis de ser fabricadas, o que é falso.

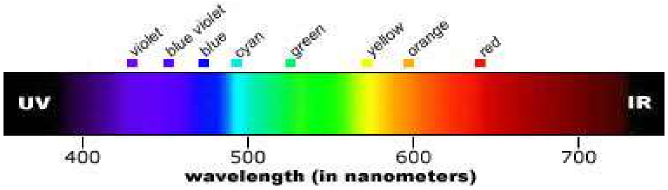
A principal diferença entre um corpo azul (iluminado por luz branca) e uma fonte emissora azul é de que o pigmento azul está a absorver o verde e o vermelho reflectindo apenas azul enquanto que a fonte emissora de luz azul emite efectivamente apenas azul. Se o objecto fosse iluminado por essa luz ele continuaria a parecer azul. Mas, se pelo contrário, ele fosse iluminado por uma luz amarela (luz Vermelha + Verde) o corpo pareceria negro.

[7] http://handprint.com/HP/WCL/color1.html

the visible spectrum

The nuclear fusion occuring within the sun produces a massive flow of electromagnetic radiation into space. Scientists describe this radiation both as oscillations in an electrical field (**waves**) and as tiny quantum packets of energy (**photons**). The distance required for one cycle in a light wave (from peak to peak) is called the **wavelength**; waves increase in frequency (decrease in wavelength) as the radiation increases in energy.

Light is *the electromagnetic radiation that stimulates the eye.* The **wavelengths of light** range from about 380 to 750 nanometers (billionths of a meter), which is a very narrow span of the sun's total radiance. The invisible radiation at higher energies (at wavelengths shorter than 380 nanometers) is called **ultraviolet** and includes x-rays and gamma rays. Lower energy radiation (at wavelengths longer than 750 nanometers) is called **infrared** or heat; at still lower frequencies (longer wavelengths) are microwaves, television and radio waves.



the visible electromagnetic spectrum

spectrum colors as produced by a diffraction grating (**IR** = infrared, **UV** = ultraviolet); for a discussion of spectral color reproduction on a computer monitor, see the **Rendering Spectra** page by Andrew Young

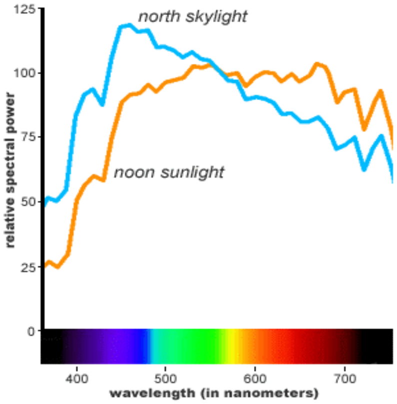
The figure shows the visible spectrum roughly as it appears in sunlight reflected from a diffraction grating (such as a compact disc), which produces an equal spacing of light wavelengths. Notice the very gradual falloff in luminosity at the near infrared (IR) end of the spectrum, and the relatively sharper falloff toward ultraviolet (UV). In fact, the boundary on the infrared side varies with the temperature of the individual (extreme cold makes us less sensitive to infrared light) and with light intensity: infrared is visible to a wavelength of 1000nm or more, if the light source is strong enough and viewed in complete darkness.

Within the spectrum, too, the **spectral hues** do not have clear boundaries, but appear to shade continuously from one hue to the next across color bands of unequal width. (When viewed as a rainbow or through a glass prism, this spacing changes: the "red" end of the spectrum is compressed and the "blue" end is expanded.) It is easier to locate the center of these color categories than the edges, and the approximate location of the basic spectral hues is shown in the figure. Note the broad span of "blue violet" and "violet," the fairly sharp transitions from "blue" to "cyan" and from "green" to "yellow," and the narrow span of "cyan" and "yellow" (which is often close to white in an actual rainbow).

The quotes I've just used to refer to spectral colors emphasize an important point. Each single wavelength of the spectrum, seen by itself at sufficient brightness in a dark surround, creates the perception of a unique hue. Yet **light itself has no color**, because the apparent color caused by the same light wavelengths can change **depending on the context** in which the light is viewed. For example, long wavelength or "red" light can, depending on context, appear red, scarlet, crimson, pink, maroon, brown, gray or even black!

This color relativity means that **color is in the mind, not in the physical world**. To mark this very basic point, color names appear in quotes whenever they are used to describe a range of light wavelengths. In all diagrams on color vision, spectrum colors are only symbolic of the different wavelengths of light.

At the earth's surface, we are largely screened from the sun's higher energy radiation by the absorbing effects of the atmosphere. In noon light, long wavelength (heat) radiation is as intense and extensive as the visible spectrum, so the gradual falloff in perceptible "red" light is due largely to our lack of visual sensitivity in the longer wavelengths. The falloff at the ultraviolet end of the spectrum is more abrupt for two reasons: the atmosphere strongly filters short wavelengths ("violet" radiation intensity falls off sharply at around 450 nm, and is only 50% at 400 nm), and the **corona and lens** of the eye become progressively more yellowed and opaque as we age, and act as a yellow filter to remove "blue" light from the light striking the retina. (Removal of the cornea in a cataract operation produces a significant increase in UV light sensitivity, called **aphakic vision**.)



color bias in daylight and twilight
the atmosphere strongly filters light below 450nm

On a sunny clear day, there is a distinct blue bias to natural light, which combines both direct sunlight and the indirect blue light of the sky. The contribution of skylight is significant: though much dimmer than the sun's disk, the visible area of the sky is approximately 100,000 times larger, which is why objects in daylight shadow are clearly illuminated. Around noon ultraviolet radiation (roughly in the range 290nm to 400nm) is at its strongest, and UV radiation causes most of the energetic effects we attribute to light at the earth's surface — everything from raging sunburn to fading paints and fabrics.

Direct sunlight — the sun's visible disk — is so brilliant that it overwhelms our color vision, making color judgments unreliable. If dimmed sufficiently, the sun appears to be very pale greenish yellow (not the deep yellow of schoolroom paintings). Around sunrise or sunset, the sun's light must pass sideways through a much thicker layer of the earth's atmosphere, and the skylight is significantly less bright, which causes a sharp reduction in the "blue" and "green" wavelengths from both sun and sky. As a result, morning or late afternoon light has a red bias, climaxing in the deep reddish colors of sunset.

These physical facts define the light stimulus that our eyes are adapted to report. The problem of translating the behavior of **light in the world** into a coherent *representation* of the world is so difficult that it is broken down into a sequence of complex perceptual and cognitive processes. The rest of this page focuses only on those processes that actually occur within the eye; **another page** introduces the psychological aspects of color vision.

design of the eye

The eye is a marvel of biological adaptation, and in large part this adaptation is designed to separate visual tasks into three independent levels of structure: the optical eye, the neural photoreceptor cells, and the chemical photopigments.

Eye. At the largest scale, the **eye** is essentially an optical camera (top diagram at right), equipped with a lens to focus light onto a photosensitive surface in its dark interior, in the same way a camera focuses light onto film.

The camera analogy primarily applies to the eye's front end: the **lens** and its transparent covering, the **cornea**, act as a compound lens to focus the image. The cornea's optical shape is maintained by gentle internal pressure from the *aqueous humor* between the cornea and lens. The cornea does most of the work in focusing light, as we discover when we swim underwater without a face mask. (Light is refracted by the change in density between air and the cornea; immersing the eye in water nullifies this light bending difference.) Because it is essential to vision, the cornea is protected by the bony brow, nose and cheek ridges nearby, and the eye's extreme sensitivity to touch.

The lens is a flexible, transparent body, with a naturally rounded shape that is stretched taut and flat along its front surface, like a trampoline canvas in its frame, by the constant tension of *zonule fibers* around its circumference. This tension flattens the lens for midrange and distance vision. To focus on nearby objects (closer than 5 meters), the *ciliary muscles* encircling the lens contract to close the opening spanned by the zonule fibers, which slackens the tension around the lens and allows it to resume its rounded shape, shortening the focal length. As people grow older, the lens hardens and does not return to its rounded shape when the ciliary muscles contract, producing the age related farsightedness called *presbyopia.*

The aperature into the eye or **pupil** is fringed by a light sensitive **iris**, which acts like a shutter to expand or contract the pupil opening from a minimum of 2mm up to a maximum of 5mm (in the elderly) to 8mm (in young adults). This can reduce the amount of light entering the eye by up to 95%. However, this represents a tiny fraction of the total range of illmination the eye can handle. The major changes in **luminosity adaptation** occur in the retina and brain; the iris makes prompt adjustments to relatively small changes in light intensity.

The rest of the eye is wrapped in a tough external coating of translucent white **sclera**, which attaches by tendons to muscles that rotate the eye within the recessed bony eye socket. The rounded shape is maintained by internal pressure from the transparent, jellylike *vitreous humor.* The inner surfaces of both the iris and the **choroid** inside the sclera are covered with a pigmented, black membrane that (1) prevents unfocused light from shining through the white of the eye, and (2) prevents light that enters the pupil from reflecting off the inside of the eye. (This pigment is lacking in albinos, causing light that is tinged the red of retinal blood to reflect back out through the pupil.)

Retina. The optics of the eye serve one purpose: to focus an image on the light sensitive **retina**, a paper thin layer of nerve tissue covering most of the inner surface of the eye (middle diagram at right, **above**). With a surface area the size of a silver dollar, and a total volume no larger than a pea, the retina is nothing like photographic film. It is actually an incredibly compact and powerful computer, a dense network of 200 million layered and highly specialized nerve cells. These capture visual information via the separate photoreceptor cells (**rods and cones**), then extensively process and filter the retinal image before sending it on to the brain. The retina is also woven throughout with tiny blood vessels that nourish the continuously active retinal tissue and give it the red color we sometimes see staring back at us in flash photographs.

The visual center of the eye, slightly to the outside of the visual axis (the focal point behind the lens), is marked by a slight depression in the retina less than 2mm wide, the **fovea centralis**. The fovea specializes in the perception of contrasty edges at an extremely high level of detail. The foveal cones are much thinner and longer than average, which makes possible an extremely close packing of cones in the fovea and eases somewhat the need for precise optical focusing in depth (front to back). Visual clarity is also enhanced by thinning and spreading apart the synoptic bodies and retinal support cells (nerves and blood vessels) over the fovea, which creates a small depression (the Latin *fovea* means "small pit") that shields the foveal cones from extraneous light scattered sideways inside the eye. This fovea is also veiled by a yellow **macular pigment**, which filters out short wavelength light from the foveal cones and appears as a slight darkening of healthy retinal tissue (right). Finally, the foveal retina contains specialized secondary cells and cell interconnections that **amplify brightness contrasts** and reduce color contrasts between neighboring cones in the fovea. Many of these adaptations seem to function primarily to reduce **chromatic aberration** and greatly increase **edge definition**.

The retina also includes several types of cells — with "colorful" names such as *midget ganglion* and *parasol cell* — which group neighboring cones and rods into **center/surround receptive fields**. These transform the individual photoreceptor outputs into contrasting **channels of color information**, and sharpen the image edge and contrast resolution based on the relative proportions of stimulation received by adjacent cones. (More of these retinal processing tasks are **described below** and on the **next page**.)

So the retina does not merely respond to light — it also **transforms and sharpens the image** before it sends the information to the brain for more complex interpretation. This processing occurs in the retina, rather than in the brain, because these "processed" color impulses can be sent through fewer optic nerve connections and with much less "noise" or error than the raw cone outputs. So the retina is quite different from photographic film and more resembles a modern digital image sensor.

Photoreceptor Cells. Vision really begins at the third level of scale, the **photoreceptor cells**. These cells are of two basic types (bottom diagram at right, **above**): the roughly 100 million **rods** adapted for dim light and night vision (**discussed below**) and the 6 million or so **cones** that give us daylight contrast and color.

Both have essentially the same structure. The cell body (including the nucleus and metabolic processes) supports an *outer segment* containing around 1000 membrane disks stacked one on top of another; each disk contains up to 10,000 photosensitive **photopigment molecules**. The *inner segment* continually produces new photopigment, embeds them in the disks, and passes them into the outer segment. The disks slowly migrate outward to the end of the outer segment, where they are metabolically broken down. At the opposite end of the cell, electrical impulses created when light strikes the photopigments are relayed via the *synoptic body* to the retina's neural network.

All photoreceptor cells are arranged with the light sensitive outer segments resting against the black **choroid**. This prevents light from reflecting back into the cones a second time, and provides a smooth, curved surface upon which an image can be precisely focused. The irregular and relatively thick layer of retinal blood vessels and nerves is woven *over* the cones rather than underneath them; we don't see the shadows of this layer because it never moves, and **constant stimuli** are completely filtered from images by the brain.

The distribution of photoreceptor cells varies considerably across different parts of the retina (diagram at right). The fovea contains a "central bouquet" of only two types of cones (R and G, **described below**); the B cones and rods are entirely excluded. This allows a tight packing of anywhere from 160,000 to 250,000 cones per square millimeter — an average cell spacing (about 2.5 to 2 microns) that equals the eye's maximum possible optical resolution. Outside the fovea, the R and G cones are mixed with B cones to provide the complete range of color vision; here color and lightness, rather than edges, determine the perception of shapes. All the cones become fatter and less densely packed, and the spacing between them increases, along the sides of the eye. This reduces optical resolution and light sensitivity where the curved surface of the retina makes it impossible for the lens to provide a crisply focused image.

The rods, in turn, are absent from the fovea but form a dense, diffuse ring of cells at about 20° around it, providing dim light vision that is very poor at resolving visual detail or texture. The density of rods remains relatively high over more than half the eye's interior surface, and is slightly higher on the nasal side of each eye, where the rods provide slightly enhanced peripheral vision in dim light.

Both types of receptors are absent in the small area of the eye known as the **blind spot**. This is a opening through the retina that allows access for blood vessels and exit for the bundled neural pathways of the optic nerve.

The eye's light receptors are easily the most complex sensory cells we have. The rods and cones are fitted with a small ionic "pump" that continuously expels ions of sodium (Na+) inside the cell as it brings ions of potassium (K+) from outside. The resulting imbalance produces a small, steady electric current across the cell body. The action of light can increase or decrease this baseline electric potential. In other words, the **rods and cones produce a continuous visual signal**, unlike other sensors which are active only when stimulated.

Photopigment Molecules. Within the outer segment of these receptor cells is the fourth and smallest level of scale, the roughly 10 million **photopigment molecules**. These are the actual agent of vision, the start of the process that turns light into color, as detailed in the **next section**.

In each rod or cone, the outer segment (**see figure**) is basically a cylindrical wrapper around a single membrane that is folded back and forth into layers, which separate into hundreds of stacked disks. The cylindrical wrapper is perpendicular to the back of the eye so that each photon must pass lengthwise through this stack of disks, which increases the probability that a photon will strike one of the 10 million or so photopigment molecules contained within each receptor cell.

Because the photopigments absorb light, they have a characteristic color — a dark, opaque pinkish color known as *visual purple.* The absorbed light causes these molecules to undergo a complex chain of reactions, beginning with a **photoisomerization** that changes the shape of the molecule, then a **bleaching** that breaks the molecule down into other substances. Bleached photopigment is a transparent yellow, which allows light to pass deeper into the outer segment and strike the photopigment molecules below.

Each molecule is looped through tiny fat pads in a single disk of the outer segment, which gently grip the photopigment; intertwined with the photopigment is a **chromophore molecule** holding it in place. When the photopigment is struck by a photon it instantly snaps or uncoils, rupturing the bond with the chromophore. This initiates an enzyme reaction that decreases the sodium ion (Na+) permeability of the cone outer membrane, which changes the electric charge along the surface of the cell and the chemical activity at synapse between the cone and retinal ganglion cells. As the number of snapping photopigments within the inner segment increases, the intensity of the nerve output from the cell also increases.

Once a photopigment is "snapped" and then bleached by the photon reaction, it must be replaced, which is apparently done by **regenerating new photopigment** from the bleached components and by growing new disks at the base of the outer segment. Less than 1% of the total amount of bleached photopigment in a cone is regenerated each second; yet surprisingly, even during intense daylight, less than 50% of the photopigment is bleached at any time.

This is the mechanism of sight: light changes the photopigment, which triggers a chemical reaction, which changes the electric charge of the cell, which changes its synaptic activity. Vision is, so to speak, an incredibly specific form of touch bound to a three dimensional array of tiny, light sensitive molecules.

As a whole, human vision performs near the theoretical limits for an optical system. A person with normal eyesight under daylight illumination can distinguish the separate lines in a grid of black and white lines 1mm apart viewed from a distance of 7 meters. The finest camera of similar aperature and focal length cannot do any better.

But this hardly supports the Creationist belief in the "divine perfection" of the eye, which is made with very crude optics, and produces a yellowed, **chromatically aberrated** and fuzzy image across most of its interior surface. These optical shortcomings are compensated for by the complex structure of the **visual field**, by continual, exploratory **eye movements**, and by extensive **filtering**, **contrast enhancement** and **cognitive interpretation** of the flow of visual images from the eye. Vision requires two eyes and two thirds of our brain to function as effectively as it does.

three plus one light receptors

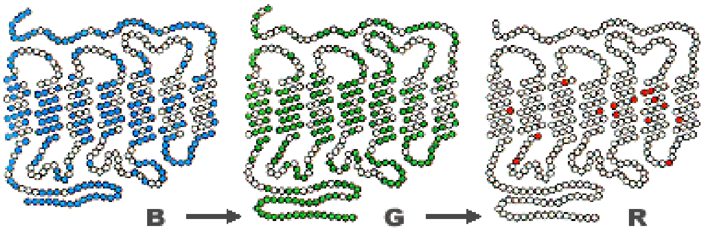
The visual receptor cells in the retina are the foundation of our visual experience. All modern **color models** and **colorimetry** are formulated as combinations of the color receptor cells.

Most of the research work on light sensing cells has been devoted to the light reactive nature of the photopigments, as this is believed to determine the fundamental light sensitivity of individual receptor cells. It is remarkable that our understanding of these photopigments is largely indirect or inferential, based on reasonable but somewhat arbitrary assumptions and convergent evidence from very different research techniques, including research using monkeys and colorblind (dichromat) humans. Even so, the current models accurately predict human color perceptions and simple **color comparisons**.

Cones. All human photopigments consist of a long necklace of amino acids, and all are variations on a single primitive *opsin* receptor molecule. The various cone photopigments (and **rhodopsin**, the photopigment in **rods**) evolved by substituting or adding amino acids within the basic opsin structure.

The exact sequence of amino acids in the cone photopigments determines the specific wavelengths of light that cause them to photoisomerize and bleach. Our color vision is built on this chemical sensitivity to a limited part of the spectrum.

As the figure shows, there is a large number of differences between rhodopsin (not shown) and the B photopigment, a similarly large number of differences between the B and G photopigments, but very few between the G and R photopigments.



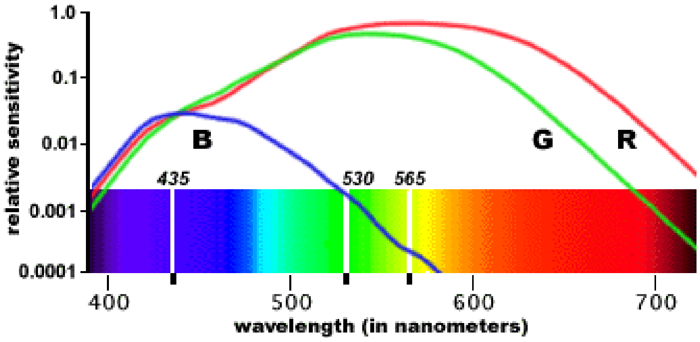
three types of photopigment molecules
colored circles show the changes in molecular structure from previous molecule (B is compared to rhodopsin [not shown], G to B, and R to G)

The individual photopigment responses to light are averaged into the total response of the cone that contains them: the **cones are the fundamental units of visual information**, not the photopigments. There are apparently *at least five* different types of cone photopigment in the eye, though each cone contains primarily one kind of photopigment with minor variations on it. As a result, the cones are commonly categorized into three types according to the photopigment they contain:

- **long wavelength** or "red" (**R**) cones (which are actually most sensitive to "greenish yellow" wavelengths around 565 nm)
- **middle wavelength** or "green" cones (**G**, most sensitive to "green" wavelengths at around 530 nm)
- **short wavelength** or "blue" cones (**B**, most sensitive to "blue violet" wavelengths at around 435 nm).

The idea that our perception of millions of colors depends on just three distinct color receptors is called the **trichromatic theory** of color vision, first proposed in the 18th century. This is the framework universally used both to **specify color stimuli** and to define **how the eye interprets color** from light.

The rather fragile chemical structure of photopigments makes them react to the absorption of a single light particle or photon. But this **sensitivity depends on the wavelength (energy) of the photon**. Each photopigment has a distinctive wavelength where it is *most likely* to react. But other wavelengths can also cause the photopigment to react, although this is *less likely* to happen and so requires on average a larger number of photons to occur.
This varying relationship between pigment photosensitivity and light wavelengths creates a unique **relative sensitivity curve** for each type of cone. As the curve gets higher, a greater proportion of photopigment is bleached at that wavelength. As we would expect from the molecular differences among the photopigment molecules, the R and G cone sensitivity curves have a very similar peak and span within the spectrum, and both differ significantly from the location and shape of the B cone curve.
The curves below show the cone responses adjusted for the yellowing of the eye lens and macular pigment (an uncertain correction that affects primarily the inferred B cone response, which is why the curve appears somewhat wobbly). They represent the relative sensitivity of the cones in the wide field retina (a 10° field of view that extends outside the fovea).



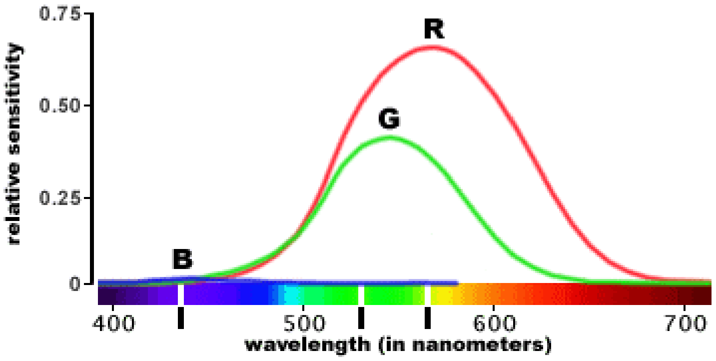
relative sensitivity curves for the three types of cones
log vertical scale, cone spectral curves from Vos & Walraven, 1974

This cone sensitivity diagram makes three important points:

- **each type of cone responds to a wide range of light wavelengths**; in fact, the response ranges of the R and G cones extend across the entire visible spectrum, although the sensitivity of the G is very low in the near infrared.
- the **response curves largely overlap** one another — in particular the R and G curves — which is the fundamental reason why "primary" colors are always either **imaginary or imperfect**.
- the **B cone sensitivity is restricted to the "cool" hues** from yellow green to blue violet, which may be the origin of the subjective difference between **warm and cool** colors.

These curves represent the cone responses relative to the sensitivity of the R cones at the wavelength where they are most sensitive. But the **cone sensitivity at any wavelength depends on the light intensity** and on the eye's **light adaptation**. Normally invisible ultraviolet or infrared radiation beyond the limits of the light spectrum can become visible if the luminance level is high enough and the light is seen in complete darkness.

The diagram uses a logarithmic or *exponential scale* on the vertical axis (each interval is ten times greater than the previous), which helps to show the detail of the curves at very low sensitivity levels. If instead we use a normal scale, it's more obvious that each type of cone responds primarily to light that is close to the cone's **wavelength of maximum sensitivity** (the three black lines below the spectrum band).



relative sensitivity curves for the three types of cones
the Vos & Walraven curves on a normal vertical scale

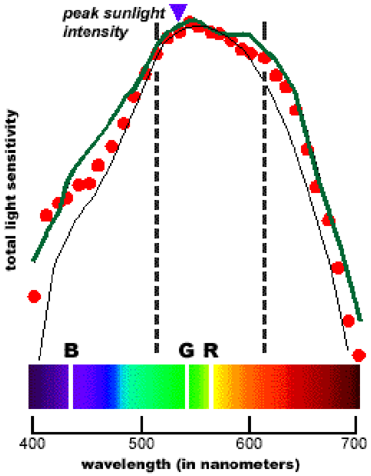
These "bell curves" mean that 10,000 photons (energy units) of light at a wavelength near the extreme of a cone's range have roughly the same stimulus effect as *one* photon at the center! These relatively narrow peak responses partly compensate for the overlap between the cone sensitivity curves, allowing good hue discrimination without sacrificing overall lightness sensitivity.

In practice, color workers in many research fields have little use for these fundamental sensitivity curves; instead they use one of many interrelated **color mixture curves** that show the proportional **mixture of three "primary" colors**, approximated by three monospectral lights, necessary to match any other monospectral wavelength. Perhaps the most interesting fact to emerge from these studies is the very small change in cone mixture proportions, in particular the **contribution of B cones**, that is sufficient to produce a significant perceptual change in the color.

The large differences in the height and spread of the curves (the probability that a cone of each type will respond) arise in part because there are **unequal proportions of R, G and B cones** in the retina. About 64% of the color receptors are long wavelength R cones, 32% are mid wavelength G cones, and 4% short wavelength B cones. Thus, a single photon is about 16 times more likely to hit an R rather than a B cone. And a yellow light — like those flashing road hazard lights — is much more likely to create any visual response, or a stronger visual response, than a pure blue or red light of equal luminance.

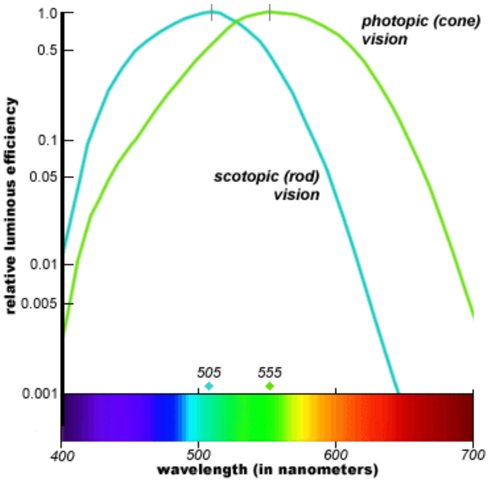
The R and G cones are in many respects neural twins: they are indistinguishable under a microscope (both look different from the B cones); they share **very similar photopigments**; and outputs from one type of cone can directly inhibit outputs from neighboring cones, which can **enhance fine contrast** or signal differences between individual cones in the fovea; and the R and G cones team up to provide us with **luminosity perception** that is separate from color perception.

So the R and G cones do nearly all the work in color vision — and the R cones more work than the G. This R > G > B order of dominance creates a **"warm" color bias** in our color experience. We'll see that this bias appears in other aspects of color vision, so it is not just an incidental result of cone proportions.



total light sensitivity in photopic (daylight) vision
for a 5° visual area; blue triangle shows approximate peak sunlight intensity when measured in wavelength units (from Kaiser & Boynton, 1995)

The diagram above, based on three different experimental measurements, shows how all three cones combine to produce our overall light sensitivity in **photopic vision** (daylight vision). This is quite close to the peak sunlight luminance (in terms of number of photons at the earth's surface) around 540 nm. However, as we'll see in a **later section**, the sunlight intensity is not the only explanation for our visual emphasis on "greenish yellow" wavelengths.



idealized photopic and scotopic sensitivity functions
CIE 1924 scotopic vision and CIE 1964 wide field (10°) photopic vision

It turns out that this **photopic sensitivity function** very closely matches the simple addition of the R and G cone sensitity curves, which is a major reason why the B cones are thought to **contribute nothing** to perception of brightness. Although this curve shows the relative sensitivity of the average human eye to different light wavelengths, it can also be interpreted as the **relative luminous efficiency** of different colors of lights. Thus, compared to a yellow green light, a scarlet light must emit 2 times as many photons, and a blue violet light 20 times as many, to appear equally bright. (This is why many emergency response vehicles are now painted yellow green instead of red — the yellow green is much easier to see, especially in dim light.)

The idealized function, which peaks at around 555nm, forms the basis of **modern photometry**, such as photographic light meters. An electronic sensor measures the intensity of light within the visible spectrum, but weights each wavelength by its relative luminous efficiency; the sum of these closely matches the apparent brightness of the light to the human eye. In effect, red and violet are the "dark" hues of the spectrum, which is why their spectral mixture (purple or violet, the **visual complement** of yellow green) is used as a shadow color by many watercolor painters.

Rods comprise a much larger group of receptor cells that provide vision in very low illumination (dark adapted or **scotopic vision**).

There are roughly 100 million rods in the human retina. They are completely **absent from the fovea** at the center of **the visual field** where daylight visual resolution is highest, and (like the cones) are more widely spaced and larger in diameter toward the edges of the retina. However, the rods form a dense ring around the fovea — which is why faint lights or stars at night become visible by looking slightly to one side of them. There are about 16 rods for every cone in the eye, but there are only about 1 million separate nerve pathways from each eye to the brain. This means that the average pathway must carry information from 6 cones *and* 100 rods! This pooling of so many rod outputs in a single signal considerably reduces scotopic visual resolution: even under optimal circumstances, rod visual acuity is only about 1/20th that of the cones, which is why it's impossible to read a book by moonlight.

Rods can affect color perception in moderately low illumination (while the cones are still active) and in large areas of color (extending outside the visual field of the rodless fovea). As shown in the diagram above, their maximum light sensitivity is around 505 nm ("blue green"), and as they first become active they shift apparent colors toward a bluish green hue, making blues appear more intense and reds appear dull or almost gray. This **Purkinje shift** (named for the Bohemian scientist who described it in 1825) is quite noticeable if you look at a familiar, brightly colored art print or flower bed around twilight as your eyes become adapted to darkness.

In daylight illumination the rods are "switched off" or *saturated.* A large proportion of the rod photopigment is bleached by normal daylight, which reduces the rod sensitivity range, and rod visual signals are drowned out by cone **luminosity information** in the same nerve pathways. But after about ten minutes of **dark adaptation** the cones stop responding completely: at night, we lose color vision, except for isolated points of higher luminosity, such as distant traffic lights or the planet Mars. We also lose acuity as the foveal cones stop responding, but this is partly compensated by the much greater number of rods ringing the fovea, allowing us to see relatively small objects in scotopic vision.

[8] http://myspace.eng.br/fis/eletr/eletr6B.asp#dip_eletr

2-) Dipolo elétrico (início da página)

Na página Eletricidade II, foram dados alguns conceitos básicos sobre **dipolo elétrico**, isto é, o conjunto de duas cargas elétricas opostas +q e -q, separadas por uma pequena distância d (na citada página está considerado 2d, mas as fórmulas aqui são ajustadas para d).

O **momento elétrico p** (não é momento mecânico) do dipolo é o vetor definido por:

$\mathbf{p} = q\,\mathbf{d}$ #II.1#, onde **d** é o vetor de módulo igual à distância d entre as cargas e sentido da negativa para a positiva. Ver representação na Figura 2.1 de um dipolo ao longo do eixo x (nesta, o vetor **p** tem graficamente o mesmo módulo de **d**, mas é apenas por questão de clareza. Depende da escala que se considera no gráfico).

Na página Eletricidade IIA, pode ser visto que o potencial elétrico de um ponto situado a uma distância r de uma carga q é dado por $V = [\ 1/(4\,\pi\,\varepsilon_0)\ ]\ .\ (q\ /\ r)$. Para um ponto M genérico conforme figura, o potencial devido ao dipolo é a diferença dos potenciais relativos às duas cargas: $V = [\ 1/(4\,\pi\,\varepsilon_0)\ ]\ .\ [(q\ /\ r') - (q\ /\ r'')] = [\ 1/(4\,\pi\,\varepsilon_0)\ ]\ q\ (r'' - r')\ /\ (r'\ r'')$. Considerando que a distância d é pequena em relação a r, as seguintes aproximações podem ser colocadas:
$r'\ r'' \cong r^2$ e $r'' - r' \cong d \cos\alpha$. E substituindo resulta:

$V = q\ d \cos\alpha\ /\ 4\,\pi\,\varepsilon_0\ r^2 = p \cos\alpha\ /\ 4\,\pi\,\varepsilon_0\ r^2$ #II.2#, onde p é o momento elétrico do dipolo.

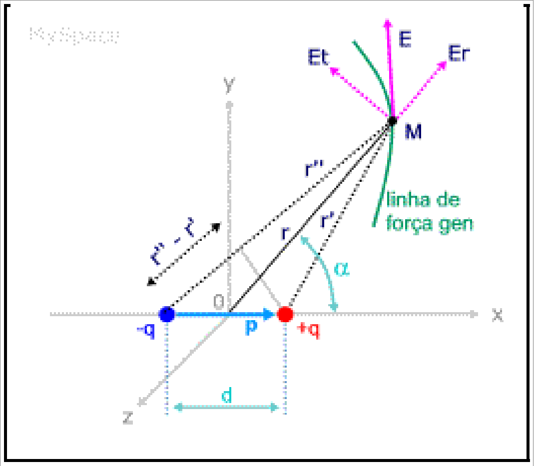


Fig 2.1: dipolo elétrico

Na mesma página é dada a relação simplificada entre campo e potencial elétrico:

$E = -\ (V_a - V_o)\ /\ X_a$, onde X_a é a distância entre os pontos de potencial a e o na direção do campo. Essa igualdade é na realidade um caso particular de uma mais genérica, dada por:

$E_x = -\ \partial V/\partial x$ #II.3#, onde E_x é o componente do vetor campo elétrico na direção x. E podemos deduzir os componentes radial e tangencial para o caso de coordenadas polares:

$E_r = -\ \partial V/\partial r$ e $E_t = -\ \partial V/\partial l$ #II.4#, onde $dl = r\ d\alpha$.

E podemos usar essas igualdades para determinar os componentes do vetor campo elétrico do dipolo.

$E_r = -\ \partial V\ /\ \partial r = 2\ p \cos\alpha\ /\ (4\,\pi\,\varepsilon_0\ r^3)$ e $E_t = -\ (1/r)\ \partial V\ /\ \partial\alpha = p \operatorname{sen}\alpha\ /\ (4\,\pi\,\varepsilon_0\ r^3)$ #II.5#.

Na Figura 2.1 esses componentes estão representados para uma linha de força genérica que passa pelo ponto M. Uma forma aproximada das linhas de força de um dipolo é dada na Figura 4.2 da página Eletricidade II.

3-) Dipolo elétrico oscilante (início da página)

Na página anterior foi dada a formulação das ondas eletromagnéticas sem mencionar como podem ser produzidas. Um dipolo elétrico pode irradiar ondas eletromagnéticas, sendo este o motivo da revisão e detalhamento dados no tópico anterior.

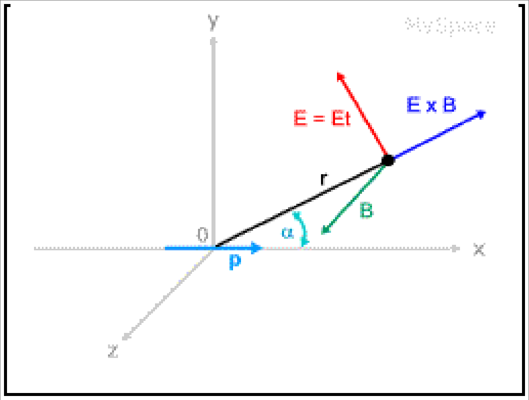


Fig 3.1

Se o momento elétrico do dipolo é constante, há apenas o campo elétrico. Se ele oscila, o campo varia com o tempo e também há um campo magnético variável conforme leis do eletromagnetismo. Isto sugere, e a prática confirma, a irradiação de ondas eletromagnéticas.

Um dipolo oscilante pode ser formado, por exemplo, pela perturbação do movimento de elétrons num átomo ou por um dispositivo comum, como uma antena para telecomunicação.

Considerando o caso prático mais comum, isto é, oscilação senoidal, o momento do dipolo oscilante é dado por:

$p(t) = p_0 \text{ sen } wt$ #III.1#.

Entretanto, o desenvolvimento matemático dos campos elétrico e magnético produzidos por um dipolo oscilante é complexo e, por enquanto, aqui não é dado. São colocadas apenas algumas aproximações e resultados obtidos.

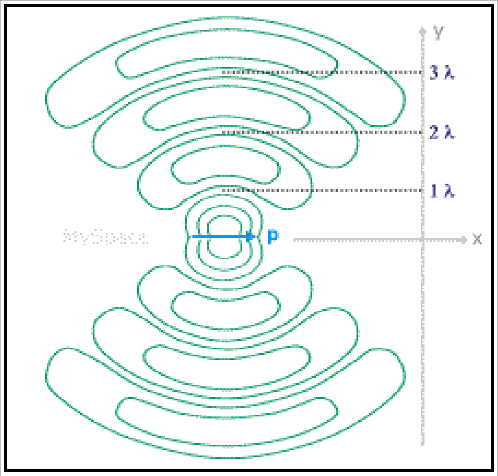


Fig 3.2

Para pequenas distâncias, o retardo devido à velocidade de propagação da onda pode ser desprezado e os componentes radial e tangencial do campo elétrico podem ser dados de forma aproximada pela substituição de p em III.1 nas igualdades II.5:

$E_r = 2\, p_0 \cos \alpha \text{ sen } wt \,/\, (4\, \pi\, \varepsilon_0\, r^3)$

$E_t = p_0 \text{ sen } \alpha \text{ sen } wt \,/\, (4\, \pi\, \varepsilon_0\, r^3)$ #III.2#.

Para maiores distâncias, as frentes de onda se aproximam do plano a a tendência é existir apenas o componente tangencial do campo elétrico conforme indicado na Figura 3.1.

E o desenvolvimento matemático resulta em:

$E = p_0 \text{ sen } \alpha\, (w/c)^2 \text{ sen}(2\, \pi\, r/\lambda - wt) \,/\, (4\, \pi\, \varepsilon_0\, r)$ #III.3#.

O campo magnético pode ser deduzido a partir da igualdade E = c B da página anterior:

$B = p_0 \text{ sen } \alpha\, (w/c)^2 \text{ sen}(2\, \pi\, r/\lambda - wt) \,/\, (4\, \pi\, \varepsilon_0\, r\, c)$ #III.4#.

A Figura 3.2 dá a forma aproximada das linhas de força do campo elétrico do dipolo em questão (é apenas um desenho aproximado. Não foi traçado por software matemático). Notar que, próximas do dipolo, parecem linhas do campo estático e, distantes, são linhas fechadas que correspondem a uma oscilação completa.

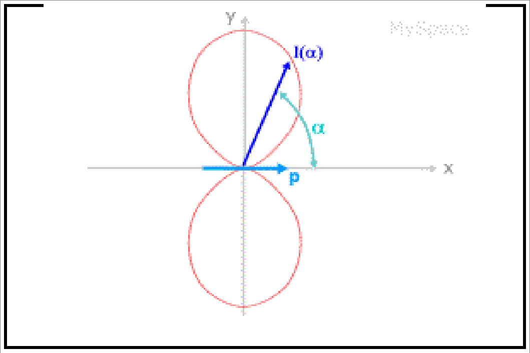


Fig 3.3

A densidade de energia (para grande distância) irradiada pelo dipolo pode ser obtida pela igualdade I.1 ($u = \varepsilon_0\, E^2$):

$u = p_0^2 \text{sen}^2\alpha\, (w/c)^4 \text{sen}^2(2\pi r/\lambda - wt)/(16\pi^2 \varepsilon_0 r^2)$ #III.5#.

E o valor médio de u é dado por:

$u_m = p_0^2 \text{ sen}^2\alpha\, (w/c)^4/(32\pi^2\varepsilon_0 r^2)$ #III.6#.

E, conforme I.2, a intensidade média da onda é dada por:

$I_m(\alpha) = c\, u_m = p_0^2 \text{ sen}^2\alpha\;\; w^4 \,/\, (32\, \pi^2\, \varepsilon_0\, r^2\, c^3)$ #III.7#.

A Figura 3.3 dá um gráfico aproximado típico da variação de $I_m(\alpha)$ com α. Podemos observar, portanto, que um dipolo não emite radiação ao logo do seu eixo. E que a curva é similar às encontradas nas especificações de ganhos de antenas reais tipo dipolo.

[9] http://scifun.chem.wisc.edu/HomeExpts/BlueSky.html

Whenever it's not completely filled with clouds, we can see that the sky is blue. As the sun rises and as it sets, it looks red. These two observations are related, as this experiment will show.

You will need the following materials:

- ❒ a flashlight
- ❒ a transparent container with flat parallel sides (a 10-liter [2½-gallon] aquarium is ideal)
- ❒ 250 milliliters (1 cup) of milk

Set the container on a table where you can view it from all sides. Fill it ¾ full with water. Light the flashlight and hold it against the side of the container so its beam shines through the water. Try to see the beam as it shines through the water. You may be able to see some particles of dust floating in the water; they appear white. However, it is rather difficult to see exactly where the beam passes through the water.

Add about 60 milliliters (¼ cup) of milk to the water and stir it. Hold the flashlight to the side of the container, as before. Notice that the beam of light is now easily visible as it passes through the water. Look at the beam both from the side and from the end, where the beam shines out of the container. From the side, the beam appears slightly blue, and on the end, it appears somewhat yellow.

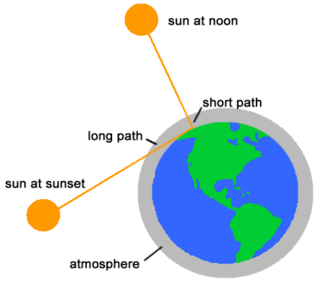
Add another ¼ cup of milk to the water and stir it. Now the beam of light looks even more blue from the side and more yellow, perhaps even orange, from the end.

Add the rest of the milk to the water and stir the mixture. Now the beam looks even more blue, and from the end, it looks quite orange. Furthermore, the beam seems to spread more now than it did before; it is not quite as narrow.

What causes the beam of light from the flashlight to look blue from the side and orange when viewed head on? Light usually travels in straight lines, unless it encounters the edges of some material. When the beam of a flashlight travels through air, we cannot see the beam from the side because the air is uniform, and the light from the flashlight travels in a straight line. The same is true when the beam travels through water, as in this experiment. The water is uniform, and the beam travels in a straight line. However, if there should be some dust in the air or water, then we can catch a glimpse of the beam where the light is scattered by the edges of the dust particles.

When you added milk to the water, you added many tiny particles to the water. Milk contains many tiny particles of protein and fat suspended in water. These particles scatter the light and make the beam of the flashlight visible from the side. Different colors of light are scattered by different amounts. Blue light is scattered much more than orange or red light. Because we see the scattered light from the side of the beam, and blue light is scattered more, the beam appears blue from the side. Because the orange and red light is scattered less, more orange and red light travels in a straight line from the flashlight. When you look directly into the beam of the flashlight, it looks orange or red.

What does this experiment have to do with blue sky and orange sunsets? The light you see when you look at the sky is sunlight that is scattered by particles of dust in the atmosphere. If there were no scattering, and all of the light travelled straight from the sun to the earth, the sky would look dark as it does at night. The sunlight is scattered by the dust particles in the same way as the light from the flashlight is scattered by particles in milk in this experiment. Looking at the sky is like looking at the flashlight beam from the side: you're looking at scattered light that is blue. When you look at the setting sun, it's like looking directly into the beam from the flashlight: you're seeing the light that isn't scattered, namely orange and red.



What causes the sun to appear deep orange or even red at sunset or sunrise? At sunset or sunrise, the sunlight we observe has traveled a longer path through the atmosphere than the sunlight we see at noon. Therefore, there is more scattering, and nearly all of the light direct from the sun is red.

For additional information, see *CHEMICAL DEMONSTRATIONS: A Handbook for Teachers of Chemistry*, Volume 3, by Bassam Z. Shakhashiri, The University of Wisconsin Press, 2537 Daniels Street, Madison, Wisconsin 53704.

[10] http://www.feiradeciencias.com.br/sala09/09_03.asp

Céu azul . . . Por quê?

Prof. Luiz Ferraz Netto
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Constatação

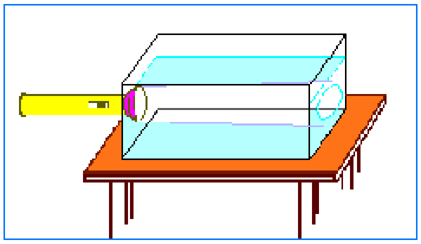
Desde que o céu não fique completamente encoberto por nuvens, poderemos ver que ele é azul. Ao nascer do sol e, pelo fim da tarde, quando ele se põe no horizonte, o céu exibe uma coloração um tanto vermelha. Essas duas observações estão relacionadas e poderão ser postas em destaque pelo experimento que detalharemos.

Material

Uma boa lanterna (as de três ou quatro pilhas com feixe estreito são as melhores), um aquário para 10 ou 15 litros com vidros bem limpos, 250 mililitros (1 xícara) de leite e uma colher de madeira de cabo longo.

Procedimento

Coloque o aquário sobre uma mesa (pequena) no centro da sala, de modo que você possa vê-lo de todos os lados. Preencha-o com água até 3/4 do seu nível total. Acenda a lanterna e mantenha-a encostada numa das paredes do aquário, ao longo de seu comprimento. Pode ser previsto um suporte para manter a lanterna assim.



Tente observar o feixe de luz que se propaga pela água. Difícil, não é? Talvez você possa ver algumas partículas de pó em suspensão na água; elas aparecem brancas. De qualquer modo que você olhe é, todavia, bastante difícil ver exatamente onde o feixe de luz atravessa a água.

Acrescente aproximadamente 60 mililitros (1/4 de xícara) de leite na água e misture com a colher de madeira.

Segure a lanterna contra a lateral do aquário, como foi feito antes. Repare que o feixe de luz agora é fácil de ser visto ao atravessar a água. Observe o feixe de luz olhando pelas outras laterais e pela face oposta a da lanterna, por onde a luz escapa do recipiente. Repare que, de lado, o feixe é visto ligeiramente azul e na extremidade oposta, aparece um pouco amarelado.

Acrescente outro 1/4 de xícara de leite na água e mexa. Agora o feixe de luz apresenta-se mais azulado quando visto de lado, e com um amarelo mais intenso olhando-se pela face oposta à entrada da luz; até mesmo um tom alaranjado pode ser observado.

Acrescente o restante do leite na água e mexa a mistura. Agora, visto de lado, o feixe de luz mostra-se bem azul e bastante laranja visto pela face oposta à da entrada da luz. Além disso, você poderá observar que o feixe de luz aparece mais espalhado do que nas primeiras observações; não é visto agora tão estreito como antes.

O que será que faz o feixe de luz da lanterna aparecer azul, quando visto de lado, e laranja quando visto de frente?

A luz normalmente propaga-se em linha reta, a menos que encontre as bordas de algum material pelo meio do caminho. Quando o feixe de luz de uma lanterna propaga-se no ar, não vemos o feixe, observando-o de lado, porque o ar é bastante uniforme (homogêneo e transparente); a luz nele propaga-se em linha reta. O mesmo é verdadeiro quando o feixe de luz caminha pela água, como nesta experiência. A água é uniforme, e o feixe a percorre em uma linha reta. Porém, se houver algumas partículas de pó no ar ou na água, poderemos observar um vislumbre do feixe porque a luz é difundida (ver nota no final do projeto) (decomposta) ao encontrar as bordas das partículas de pó.

Quando você acrescentou leite na água, você acrescentou nela muitas partículas minúsculas. Leite contém muitas partículas minúsculas de proteína e gordura que ficam em suspensão na água. Estas partículas difundem a luz e fazem o feixe da lanterna tornar-se visível quando visto de lado. Cores diferentes de luz são separadas, nesse espalhamento, em ângulos diferentes. Luz azul é desviada da direção original muito mais que a laranja ou a luz vermelha. Como nós vemos a luz difundida na direção perpendicular ao feixe, e como a luz azul é a que se difunde mais (sofre maior desvio), o feixe aparece azul. Uma vez que o laranja e o vermelho são menos difundidos, essas cores caminham em linha reta seguindo mais de perto o feixe inicial de luz branca. Por isso, quando você olha diretamente no feixe de luz da lanterna (de frente), aparece laranja ou vermelho, ou seja, o que resta da luz branca.

O que tem esta experiência a ver com céu azul e com o pôr-do-sol laranja?

A luz que você vê quando você olha o céu é a luz solar, que é espalhada por partículas de pó na atmosfera. Se não houvesse nenhuma difusão (espalhamento em cores), toda a luz proveniente do Sol cairia em linha reta para a Terra e o céu apareceria escuro, como ocorre à noite. A luz solar é difundida pelas partículas de pó, da mesma maneira como a luz da lanterna é difundida pelas partículas de leite nessa experiência.

Olhar para o céu é como olhar o feixe da lanterna de lado: você está olhando luz difundida que é azul. Quando você olha diretamente para o Sol se pondo no horizonte, do mesmo modo que olhou a luz da lanterna de frente, você estará observando apenas a luz que é bem pouco difundida (desviada), ou seja, o laranja e o vermelho.

Qual a causa para o Sol aparecer com tonalidade laranja ou até mesmo vermelho ao pôr-do-sol ou ao amanhecer?

Ao pôr-do-sol ou ao amanhecer, a luz solar que nós observamos percorreu um caminho bem mais longo através da atmosfera terrestre que a luz solar que nós vemos ao meio-dia. Nesse longo trajeto muitas cores foram difundidas (e portanto retiradas do feixe de luz branca), sobrando para nossos olhos parte do amarelo e luz vermelha. E é o que vemos!

[11] http://asd-www.larc.nasa.gov/Outreach/greenhouse/red_sky.html

Red Sky, Blue Sky

Description:

Milky water is used to simulate a sunset and the blue sky.

Objective:

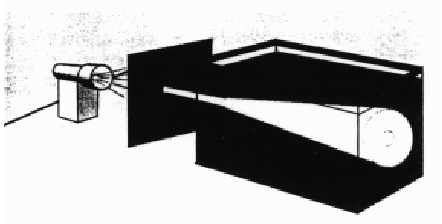
To illustrate how the gases in the atmosphere scatter some wavelengths of visible light more than others.

Materials:

- Aquarium
- Stirrer
- Flashlight
- Opaque card with hole
- Water
- Milk
- Eye dropper
- Dark Room

Procedure:

1. Fill the aquarium with water and set up the demonstration as shown in the illustration.



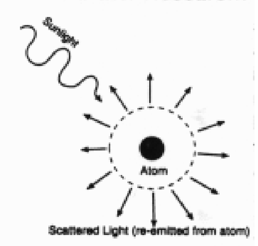
2. Add a few drops of milk to the water and stir the water to mix the two liquids. You may have to add more drops to achieve the desired color change effect. Refer to the discussion for more information.
3. Darken the room and turn on the flashlight.
4. Observe the color of the light coming from the flashlight. Next, observe the color of the light as it comes directly through the aquarium. Observe the color of the liquid from the side of the aquarium.

Discussion:

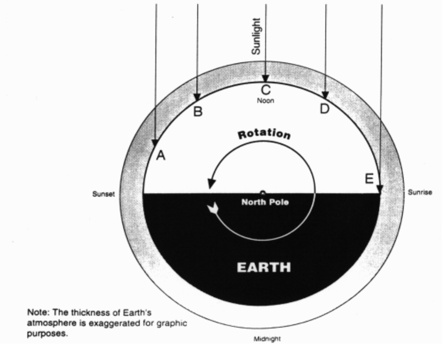
One of the standard "why" questions children ask is, "Why is the sky blue?" Sunlight has all of the rainbow colors: red, orange, yellow, green, blue, and violet. Earth's atmosphere contains molecules of gas that scatter the blue colors out of the direct path of sunlight and leave the other colors to travel straight through. This makes the Sun look yellow-white and the rest of the sky blue. This effect is accentuated when the Sun is low in the sky. At sunrise and sunset, sunlight has to penetrate a much greater thickness of atmosphere than it does when it is overhead. The molecules and dust particles scatter almost all of the light at sunrise and sunset--blue, green, yellow, and orange--with only the red light coming directly through to your eyes; so, the Sun looks red. **Caution:** Never stare directly at the Sun.
In this demonstration, the suspended particles of milk scatter the light like the molecules in Earths atmosphere. When the flashlight beam is viewed directly through the water, the blue wavelengths of light are scattered away from the beam of light, leaving it yellowish. Increasing the amount of milk simulates smog and the Sun will look red. Viewing the water from the side reveals a very subtle grey-blue hue. **Note:** Because of individual color sensitivity, some people may not be able to see the bluish hue.

For Further Research:

When energized by sunlight, oxygen and nitrogen atoms in the atmosphere re-emit (scatter) light in all directions, causing the entire atmosphere above us to be lighted by sunlight. Violet light is scattered the most and red light the least (1/10th as much). Because our eyes are not very sensitive to violet light, the sky appears blue.



- Draw a diagram on a chalkboard or overhead transparency like the one shown below in which you are looking down at Earth from a position far above the North Pole. Measure the difference in atmospheric thickness the Sun's rays must penetrate to reach each location on Earth's surface in the diagram below. Which ray has the greatest distance to travel through the atmosphere to reach Earth's surface?
- Pretend you are standing at each location looking toward the Sun. What color should the Sun be?
- What is the approximate local time for each location?



[12] http://teachers.web.cern.ch/teachers/archiv/HST2002/smallexp/krug/Rayleigh.htm

RAYLEIGH-scattering in a very simple experiment

RAYLEIGH-scattering is the cause of the blue sky and the orange sunset.

If p is the scattering-probability and λ is the wavelength of radiation, than is

.The probability for scattering is very high for a short wavelength.

That's why the blue part of the white sunlight is scattered all over the sky and sometimes –it depends on the way through the atmosphere and some meteorological facts- it is so strong that the sunlight is visible in white minus blue: orange.

When it is useful?

It is possible to show the effect every time to show little children why the sky is blue.

And it is possible too, if you want to explain it by using the word RAYLEIGH-scattering.

Then it sounds very professional.

Which material you need?

-one small aquarium

-water

-one very normal lamp with focus, maybe a torch

-a little bit of coffee-whitener (no milk, and really only a very little bit)

The rest is shown here

The view from the left side shows the orange light.

Show before, that the light is white!

The view from the top shows a light-blue cone from the right to the left.

Notice

RAYLEIGH-scattering is also visible if you watch tobacco smoke.

The smoke direct from the tobacco is blue! …

After inhaling in a humid body and exhaling, the size of particles gets bigger.

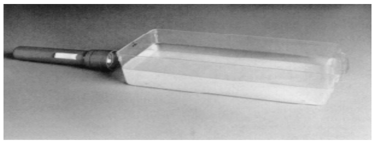
RAYLEIGH-scattering never happens. The smoke is gray or brown.

[13] http://www.exploratorium.edu/snacks/blue_sky.html

SNACKS EXPLORATORIUM SNACKS

Blue Sky

Now you can explain why the sky is blue and the sunset is red



When sunlight travels through the atmosphere, blue light scatters more than the other colors, leaving a dominant yellow-orange hue to the transmitted light. The scattered light makes the sky blue; the transmitted light makes the sunset reddish orange.

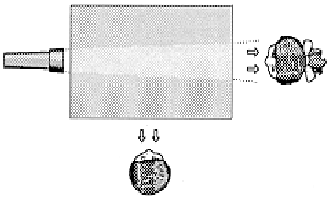
materials

- ✔ **A transparent plastic box,** or a large beaker, jar, or aquarium
- ✔ **A flashlight or projector** (either a slide or filmstrip projector)
- ✔ **Powdered milk**
- ✔ **Polarizing filter** (such as the lens from an old pair of polarized sunglasses)
- ✔ **Blank white card** for image screen
- ✔ **Paper hole-punch**
- ✔ **Optional:** Unexposed (black) 35 mm slide or photographic film, or an index card cut to slide size

assembly

(15 minutes or less)

Fill the container with water. Place the light source so that the beam shines through the container. Add powdered milk a pinch at a time; stir until you can clearly see the beam shining through the liquid.



to do and notice

(15 minutes or more)

Look at the beam from the side of the tank and then from the end of the tank. You can also let the light project onto a white card, which you hold at the end of the tank. From the side, the beam looks bluish-white; from the end, it looks yellow-orange.
If you have added enough milk to the water, you will be able to see the color of the beam change from blue-white to yelloworange along the length of the beam.

If you want to look at a narrower beam of light, use a paper hole-punch to punch a hole in the unexposed black slide or in a piece of 35 mm film, or even in an index card cut to size. Place the slide, film, or index card in the projector. (Do not hold it in front of the lens.) Focus the projector to obtain a sharp beam.

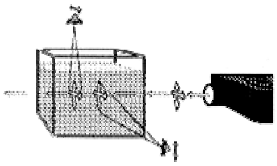
what's going on?

The sun produces white light, which is made up of light of all colors: red, orange, yellow, green, blue, indigo, violet. Light is a wave, and each of these colors corresponds to a different frequency, and therefore wavelength, of light. The colors in the rainbow spectrum are arranged according to their frequency: violet, indigo, and blue light have a higher frequency than red, orange, and yellow light.
When the white light from the sun shines through the earth's atmosphere, it collides with gas molecules. These molecules scatter the light.
The shorter the wavelength of light, the more it is scattered by the atmosphere. Because it has a shorter wavelength, blue light is scattered ten times more than red light.
Blue light also has a frequency that is closer to the resonant frequency of atoms than that of red light. That is, if the electrons bound to air molecules are pushed, they will oscillate with a natural frequency that is even higher than the frequency of blue light. Blue light pushes on the electrons with a frequency that is closer to their natural resonant frequency than that of red light. This causes the blue light to be reradiated out in all directions, in a process called *scattering*. The red light that is not scattered continues on in its original direction. When you look up in the sky, the scattered blue light is the light that you see.
Why does the setting sun look reddish orange? When the sun is on the horizon, its light takes a longer path through the atmosphere to your eyes than when the sun is directly overhead. By the time the light of the setting sun reaches your eyes, most of the blue light has been scattered out. The light you finally see is reddish orange, the color of white light minus blue.
Violet light has an even shorter wavelength than blue light: It scatters even more than blue light does. So why isn't the sky violet? Because there is just not enough of it. The sun puts out much more blue light than violet light, so most of the scattered light in the sky is blue.

Scattering can polarize light. Place a polarizing filter between the projector and the tank. Turn the filter while one person views the transmitted beam from the top and another views it from the side. Notice that when the top person sees a bright beam, the side person will see a dim beam, and vice versa.

You can also hold the polarizing filter between your eyes and the tank and rotate the filter to make the beam look bright or dim. The filter and the scattering polarize the light. When the two polarizations are aligned, the beam will be bright; when they are at right angles, the beam will be dim.

Scattering polarizes light because light is a transverse wave. The direction of the transverse oscillation of the electric field is called the direction of polarization of light.



The beam of light from the slide projector contains photons of light that are polarized in all directions. horizontally, vertically, and all angles in between. Consider only the vertically polarized light passing through the tank. This light can scatter to the side and remain vertically polarized, but it cannot scatter upward! To retain the characteristic of a transverse wave after scattering, only the vertically polarized light can be scattered sideways, and only the horizontally polarized light can be scattered upward. This is shown in the drawing.

[14] http://www.draco.scsu.edu/images/finished_graphics/sunset.html

THE SUNSET EXPERIMENT

GRADE: 5 – adult

CONCEPT:

The concept presented in this demonstration is the phenomenon called "scattering". When sunlight passes through the Earth's atmosphere, much of the light is picked up by particles in the air and given out again in some other direction.
The experiments shown, in agreement with the theory of scattering, that the shortest waves are scattered more readily than longer waves.

MATERIALS:

1. Water trough with glass slides (aquarium will work)
2. Light source which will cast a beam of white light (slide projector)
3. 40 grams of sodium thiosulfate
4. 2 to 4 millimeters of concentrated sulfuric acid H2SO4

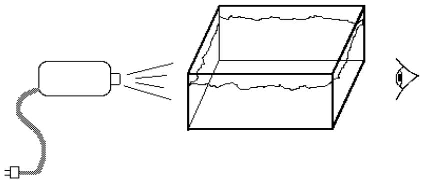
PROCEDURE:

1. Fill the trough with water and send the light beam through the trough.
2. Send the light beam through the trough.
3. Dissolve the 40 grams of sodium thiosulfate in the water-filled trough (2 gal water).
4. Add the sulfuric acid and sir to mix.

As the microscopic sulfur particles begin to form, scattered blue light will outline the beam through the trough. A little later when more particles have formed, the entire body of water will appear light blue, due principally to multiple scattering. Light scattered out of the central beam of light is scattered again and again before emerging from the trough. At first the transmitted light looking at the source through the tank of water appears white. Later, as more scattering takes out the shorter wavelengths, the disk of light representing the sun turns yellow, then orange, and finally red.

NOTE:

Allow time for the experiment to occur, after adding the H2SO4. Do not add more acid until you are sure it is needed (if no change is noticed after 3 minutes).



ANALYSIS:

The shorter waves are scattered more readily than longer waves. The shorter waves of violet and blue are scattered the most as sunlight enters the Earth's atmosphere giving the sky its blue color. When the sun is near the meridian (directly south), the sunlight passes through a relatively short air path. As a result, very little violet and blue are scattered away and the sun appears white. As sunset approaches, however, the direct sunlight has to travel through an ever-increasing air path. The result is that an hour or so before sundown, practically all of the blue and violet have been scattered out and owing to the remaining colors, red, orange, yellow and a little green, the sun appears yellow. At sunset, the direct rays must travel through so many miles of air that all but red are completely scattered out and the sun appears red. At this time, the sky overhead is still light blue..

[15] http://www.physics.brown.edu/physics/demopages/Demo/optics/demo/6f4010.htm

6f40.10 Sunset Rayliegh Scattering

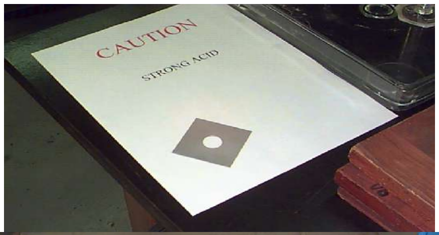
PURPOSE: To show Rayliegh scattering with a colloidal sunset demonstration.

DESCRIPTION: The light from a slide projector serving as a white light source passes through an aquarium tank and hits a nearby screen. A circular metal slide is inserted into the slide projector to produce an image shaped like the sun.
The aquarium tank is filled with 6750 g water and 135g hypo (Sodium Thiosulfate). The speed of the colloidal sunset reaction is **EXTREMELY SENSITIVE** to the temperature of thw water/hypo mixture. Therefore, it is important that the aquarium is filled with the water the evening before the demo is performed to insure that on the day of the demo the water has sat long enough overnite and has precisely acheived equilibrium with room temperature. If the water is slightly warmer than room temperature then the colloidal reaction will occur much too quickly, and vice versa, if the water is slightly colder than room T then the colloidal reaction will form much too slowly.
At the time of the demo add .5 ml concentrated HCl or Sulfuric acid is carefully to the hypo/water mixture. When the chemicals mix they begin to form a suspension of sulfur particles which act as scattering centers for the light, especially blue light at first. This leaves the light on the screen with a yellowish tint. As time passes the sulfur particles grow in size, becoming larger, and they scatter more light. But, in additon to scattering more light, the larger the colloidal particles grow the wavelength of the selectively scattered light becomes longer, changing the light on the screen to a bright red. Ultimately most light is scattered, leaving no light on the screen.

It takes about 5 minutes for the screen to go dark red. While that is happening you can talk about the sky being blue, the sun red at sunset, and even why the moon takes on a red tint when it is near the horizon and during a lunar eclipse.

The scattered light can be seen to be polarized by rotating a polaroid sheet in the light path.

EQUIPMENT: as photographed.
SETUP NOTES:
TYNDALL'S EXPERIMENT - COLLOIDAL SUNSET
D. Tattersfield, Projects and Demonstrations in Astronomy, p.109.
Haym Kruglak, A Simplified Sunset Demonstration, TPT 11, 559, (1973).
Marla H. Moore, Blue Sky and Red Sunsets, TPT 12, 436-437, (1974).
Jay S. Huebner, Tricks of the Trade: "A Golden Oldie" - Projecting a Sunset, TPT 32, 147 (1994).
E-Qing Zhu and Se-yeun Mak, Demonstrating Colors of Sky and Sunset, TPT 32, 420-421 (1994).
Sutton, Demonstration Experiments in Physics, L-46 Scattering of Light, 387-388.



Why is the sky blue? (Part I)

By David Harris

You've asked this question before, or heard somebody else ask it. It seems like the most frequent of frequently asked questions. But last time you heard the question, did you really get the answer?

In case you missed it and are too embarrassed to ask the question of somebody else, here is the lowdown.

The first thing to say is that the color of the sky has nothing to do with a reflection off the water as many people think! In fact, it works the other way around; water often appears blue because it is reflecting the sky. This doesn't get us any closer to the answer but at least it puts one myth to rest.

Just in case you don't know this yet, light from the sun is made up of a spectrum of colors that all continuously merge into each other. The human eye can't see the infinity of distinctions between different colors and, to our eyes, sunlight is made up of roughly seven colors: red, orange, yellow, green, blue, indigo and violet. The difference between the different colors, on a physical level as opposed to a perceptual one, is that different colors are light of different wavelengths and frequencies. The blue end of the spectrum has the highest frequency and the red end has the lowest frequency.

Although light seems to travel straight through air without any interruption, the air molecules as well as any contaminants such as water droplets or smog impurities "scatter" light. That means they deflect the light so that it changes direction. However, different colors are more affected by scattering than others. Blue light is scattered most and red light is scattered least.

Another point to remember is that we only see light because it hits our eyes. This may seem obvious but it is easy to forget when we think about the exact details of how light travels and how we observe things.

We now have the basic ideas we need to combine to explain why the sky is blue. If there were no atmosphere, the sky would seem dark like in space because the only light coming into your our eyes would be that coming in a straight line from stars. But on Earth, the atmosphere is scattering light all the time. This means some light that normally would have missed our eyes is actually deflected straight towards us. Because blue light is scattered more, the light coming into our eyes after deflection is more likely to have been blue light rather than red light.

So when we look into the sky but not directly towards the sun, there light coming into our eyes appears blue and is actually the blue component of light that has come from the sun.

Now you may ask a trickier question: why is the sky red at sunset?. It turns out that the answer uses the same basic physics but the situation is slightly different. You maybe able to work it out yourself or else you can wait until next week for the second part of the story.

By David Harris

Last week we talked about why the sky is blue in the daytime. The second most frequently asked question, following close behind the first, is "If the sky is blue, why are sunsets red?"

The answer comes from exactly the same physics just applied to a slightly different scenario. Remember that blue light scatters more than other colors of light. This means that during the day, the indirect light coming to your eyes is more likely to be blue than any other color.

At sunset, the situation is slightly different. Most of the light you notice on the horizon around the setting sun is coming toward you fairly directly. In this case the blue light has actually been scattered away from you, leaving just the reds, oranges and yellows. If you are observant you would have noticed that even though the sunset is red, the sky above you generally has a blue tinge to it.

So the color of the sky really depends on how close to a straight path the light has to travel from the sun to your eyes. The more direct, the redder the light, the longer the path, the bluer the light.

Just in case you are not convinced by this explanation, or if you are wondering how to do an experiment based on this idea, here is something to try. You can simulate the sky with all the molecules acting as scattering particles on a much smaller scale.

The amount of scattering that causes the sky to take on a color only occurs because there is so much atmosphere for the light to pass through. To do a table-top experiment, you need to increase the amount of scattering. The best way to do this is to use a large container of water made of a transparent material such as a plastic or glass. Try to find the longest container you can. Depth and width are not so important.

Add a few drops of milk to the water and mix it in properly. Be careful not to add too much milk. You really only need a small amount. For the largest containers even a few teaspoons will be too much. You can always add more milk later but it's pretty hard to remove it once it's there!

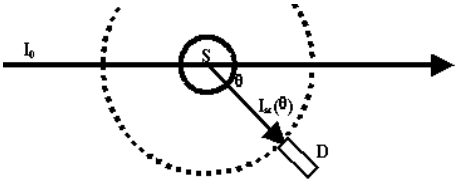
Now you just have to take a torch and shine it in one end of the container. Have a look at the diagram below. Now all you have to do is look at the container from different angles. You should notice that the color of the water appears to change from blue to red along the length of the container. This is because the blue light is the first to be scattered and then toward the end of the container, most of it is gone, leaving just the red. Try doing the experiment in a darkened room if you have trouble seeing the colors. I couldn't believe how well this worked when I first tried it!

If you look in the opposite end of the container toward the torch, you should see the torch appearing much the same color as the sun during the day. The color you see around it depends a lot on exactly how much milk you have added but it can range from a red sunset to a fairly blue sky color.

Read back over last week's article as well as this weeks and see how the ideas all combine together to explain what you can see. There are a lot of different effects you can see in the skies and a lot of them have to do with this idea of light scattering.

Keep an eye out for more and you'll soon discover you can begin to explain them yourself.

Light Scattering



Background

The phenomenon of light scattering is encountered widely in everyday life. For example light scattering by particles in the atmosphere gives rise to the blue color of the sky and the spectacular colours that can sometimes be seen at sunrise and sunset. These are all examples of static light scattering since the time-averaged intensity of scattered light is observed.

In general, interaction of electromagnetic radiation with a molecule leads either to absorption (forms the basis of spectroscopy) or scattering the radiation. Scattering results from the interaction of the electrons in the molecules with the oscillating electric field of riadiation. Thus a dipole is induced in the molecules which oscillates with the electric field. Since an oscillating dipole is a source of electromagnetic radiation, the molecules emit light, the scattered light. Almost all of the scattered light has the same wavelength as the incident radiation and comes from elastic (or Rayleigh) scattering.

Experimental Setup

Our light scattering hardware setup consists of a commercial equipment for simultaneous static and dynamic experiments by ALV-Laservertriebsgesellschaft (Langen, Germany). We use the blue line (488 nm) of a Coherent 70/2 Innova Ar ion laser at a power output of 0,1-200 mW. The primary beam's intensity and position is monitored by means of a beam splitter and a four-segment photodiode. The thermostated sample cell is placed on a motor-driven presicion goniometer (±0,001°) which enables the photomultiplier detector to be moved accurately from 20° to 150° scattering angle.

Static Light Scattering

small molecules, i. e. point scatterers

In static light scattering experiments the time-averaged (or 'total') intensity of the scattered light is measured, and for solutions is related to the time-averaged mean-square excess polarizability which in turn is related to the time-averaged mean-square concentration fluctuation. The reduced integrated scattering intensity Kc/R(q) is calculated from the absolute photon count which is recorded simultaneously with the measurement of the TCF (see below). K is an optical constant (among some constants it depends on the square of the refractive

index increment of the solute and the square of the refractive index of the solvent), c is the mass concentration of the solution, and R(q) is the Rayleigh ratio. For the calculation of the latter the instrument is calibrated by measuring the scattered intensity from toluene. Refractive index increment measurements of the samples are carried out with a Brice-Phoenix differential refractometer, equipped with a 488 nm interference filter. This apparatus is calibrated with solutions of common salts or poly(ethylene glycol).

large molecules

In the section above it was assumed that the solvent and solute molecules act as point scatterers, what means that they are much smaller then the wavelength of the incident light. This assumption may apply to solvent molecules in most cases but it is inappropriate for polymer solute molecules or aggregates (e. g. micelles). If the dimension of the solute molecule exceeds 1/20 of the wavelength a remarkable interference of the scattered light from one molecule occurs. It can be shown that the phase difference in the scattered light vanishes only at zero scattering angle. In order to account for such interference effects, a particle scattering factor P(q) is introduced and is given by the ratio P(q)=R(q)/R(q=0). Since scattered intensity at zero angle cannot be detected, analytical expressions for P(q) are required, so that an appropriate extrapolation to zero can be performed.

Conclusion: The angle dependency of Kc/R(q) contains information about the shape of the solute molecules.

Dynamic Light Scattering (Photon Correlation Spectroscopy)

Whilst static light scattering measurements provide a wealth of information (e.g. weight-average molar mass (Mw), second osmotic virial coefficient (A2) and z-average radius of gyration (<s2>z)), still more can be obtained by considering the real-time random (i. e. Brownian) motion of the solute molecules. This motion gives rise to a Doppler effect and so the scattered light possesses a range of frequencies shifted very slightly from the frequency of the incident light (this phenomenon is called quasi-elastic scattering). These frequency shifts yield information relating to the movement (i. e. the dynamics) of the solute molecules. A very popular means of monitoring the motion of solute molecules is to record the real-time fluctuations

in the intensity of the scattered light in terms of the intensity time-correlation function.

The intensity time-correlation functions (TCF) g2(t) are recorded with an ALV-5000 multi tau digital correlator with 256 channels. The installed software (CONTIN2DP) allows an on-line inverse Laplace transformation of the TCFs and yields the distribution of contributing relaxation times in the investigated sample. Further the TCFs can be analyzed in terms of a cumulant or stretched-exponential fit

Dynamic light scattering measurements yield hydrodynamic properties of the solute, e. g. the z-average of the translational diffusion coefficient (Dz) which is related to the hydrodynamic radius by the Stokes-Einstein equation.

Updated by JZ in 2/22/2001

[16] http://dicasdequimica.vilabol.uol.com.br/sais.html

SAIS:

São compostos iônicos que possuem pelo menos um cátion diferente de H^+ e um ânion diferente de OH^-.

O sal é formado através de uma reação entre um ácido e uma base; onde os íons H^+ e OH^- reagem para formar a água; e o ânion do ácido reage com o cátion da base, formando o sal.

Há uma reação entre um ácido e uma base, dar-se o nome de reação de neutralização.

Veja os exemplos a seguir:

$HCl + NaOH$ ---------> $NaCl + H_2O$

$H_2SO_4 + 2\ LiOH$ --------> $Li_2SO_4 + 2\ H_2O$

Classificação dos sais quanto à presença de oxigênio:

- Oxissais (Sais Oxigenados) » Apresentam oxigênio em sua molécula. Ex: Na_2SO_4, $AlPO_4$.

- Sais não oxigenados » Não apresentam oxigênio em sua molécula. Ex: NaCl, $CaCl_2$.

Classificação dos sais quanto ao número de elementos:

- Sais Binários » Apresentam dois elementos químicos em sua composição. Ex: KCl, Al_2S_3.
- Sais Ternários » Apresentam três elementos químicos em sua composição. Ex: Na_2SO_4, $Ba_2P_2O_7$.
- Sais Quaternários » Apresentam quatro elementos químicos em sua composição.Ex: $Ca(OCN)_2$.

Classificação dos sais quanto à natureza dos íons:

- Sais Neutros (Normal) » Não apresentam em sua composição nem H^+ e nem OH^-. Ex: NaCl, $BaSO_4$.
- Sais Ácidos (Hidrogeno-sal) » Apresentam em sua composição dois cátions, sendo um deles o H^+, e um só tipo de ânion, sendo diferente de OH^-. Ex: $NaHCO_3$, K_2HPO_4.
- Sais Básicos (Hidróxi-sal) » Apresentam em sua composição dois ânions, sendo um deles o OH^-, e um só tipo de cátion, sendo diferente de H^+. Ex: Ca(OH)Cl, $Fe(OH)SO_4$.
- Sais Duplos (Misto) » Apresentam em sua composição dois cátions diferentes de H^+ ou dois ânions diferentes de OH^-.
- Sais Hidratados » Apresentam em sua composição moléculas de água. Ex: $CuSO_4$*5 H_2O, $CoCl_2$*2 H_2O.

Classificação dos sais quanto à solubilidade em água:

Solubilidade em Água	
Sólúveis (como regra)	**Insolúveis (principais excessões à regra)**
Nitratos (NO_3^-) Acetatos (CH_3COO^-)	
Cloretos (Cl^-) Brometos (Br^-)	AgCl, $PbCl_2$, Hg_2Cl_2, AgBr, $PbBr_2$, Hg_2Br_2.
Iodetos (I^-)	AgI, PbI_2, Hg_2I_2, HgI_2, BiI_2.
Sulfatos (SO_4^{-2})	$CaSO_4$, $SrSO_4$, $BaSO_4$, $PbSO_4$.
Sais de metais alcalinos e de amônio	
Insolúveis (como regra)	**Solúveis (principais excessões à regra)**
Sulfetos (S^{2-})	Os dos metais alcalinos, alcalinos terrosos e de amônio. Exemplos: K_2S, CaS, $(NH_4)_2S$.
Hidróxidos (OH^-)	Os dos metais alcalinos, alcalinos terrosos e de amônio. Exemplos: NaOH, KOH, NH_4OH.
Carbonatos (CO_3^{2-})	Os dos metais alcalinos e de amônio. Exemplos: Na_2CO_3, K_2CO_3, $(NH_4)_2CO_3$.
Fosfatos (PO_4^{3-})	Os dos metais alcalinos e de amônio. Exemplos: Na_3PO_4, K_3PO_4, $(NH_4)_3PO_4$
Sais não - citados	Os dos metais alcalinos e de amônio.

[17] http://www.math.ubc.ca/~cass/courses/m309-04a/sky-colours.pdf
[18] http://irina.eas.gatech.edu/ATOC5235_2003/Lec9.pdf