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449. Black body radiation

The term *black body* is applied to all bodies capable of absorbing all radiations which they receive, and transforming them integrally to heat. It can be represented very approximately by a thick layer of carbon black.

Conversely, when heated, the black body emits a *continuous light spectrum* whose characteristics depend on the *absolute temperature* T.(1) The absolute temperature is that measured from the absolute zero(2) at $-273°$C. That is $T = t + 273°$ where t is the centigrade temperature measured with reference to melting ice.

The energy at each wavelength emitted by the black source depends on the temperature to which the source is heated. The primary energy flux per cm² of the source, or *radiance* r is given by Planck's formula

$$r_{\lambda T} = \frac{C_1}{\lambda^5 \left(e^{\frac{C_2}{\lambda T}} - 1 \right)}$$

where $C_1 = 3{\cdot}70 \times 10^{-5}$ erg/sec/cm² or $3{\cdot}70 \times 10^{-12}$ watt/cm² and C_2 is 14,320, λ being measured in μ. T is the absolute temperature and e is the Napierian logarithm base.

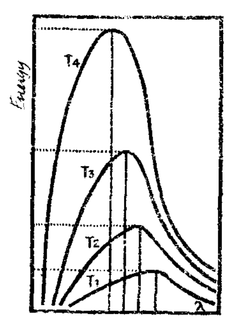

FIG. 56. Emission of black body at increasing temperatures, T_1, T_2, T_3, T_4

The *isothermal* curves obtained with radiance on the ordinates and wavelength on the abscissae have the shape shown in Fig. 56: they show that the ***emitted energy becomes much greater as the temperature is raised.***

In addition, the ***wavelength of the emission maximum is displaced towards the shorter wavelengths as the temperature increases***, the other wavelengths following in a similar way. This is a photographically important phenomenon whose practical result is that the more the temperature is raised the richer the radiation in violet rays, and conversely, at lower temperatures the more red radiated. The *colour of an incandescent* black body therefore varies with the temperature; as this increases, it passes from red to white.

The product of the maximum wavelength λ_m by the absolute temperature is a constant (Wien's law): $\lambda_m T = A = 2,884,000$, λ_m being measured in mμ.

It is therefore easy to calculate λ_m at various temperatures.

T	λ_m
1000°K	2884 mμ infra-red
2000°K	1442 mμ infra-red
3000°K	961 mμ infra-red
4000°K	721 mμ red
5000°K	577 mμ yellow
6000°K	360 mμ ultra-violet

If the ordinates at $\lambda = 590$ mμ are brought to the same value, the curves of Fig. 57 are obtained, which enables spectral composition of light emitted by a black body at various temperatures to be compared.

The *total emission* per cm² per second is measured by the area described by the isothermal curve, and is calculated by Stefan's formula $E = \sigma T^4$ where $\sigma = 5{\cdot}7 \times 10^{-12}$ watts/cm² or 1364×10^{-12} cal/cm²/sec.

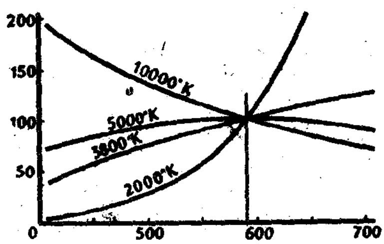

FIG. 57. Isotherms in the visible spectrum (ordinates brought together at 590 mμ).

449b. Actual sources

The emission of a black body represents an ideal case which is never realized with actual sources.

If B_T is the brightness[8] of an incandescent *non-black body*, and $\mathcal{B}_T$ the brightness of a black body at the same temperature T, then $B_T = \mathcal{B}_T\alpha$ where α is the *absorption coefficient* of the non-black body. As α is always < 1 the brightness B_T is lower than that of the black body. It follows that the spectral brightness of an actual source $b_{\lambda T}$ and the absorption factor $\alpha_{\lambda T}$ have at each individual wavelength, a constant relationship at the same temperature, equal to the spectral brightness $b_{\lambda T}{}^*$ of a black body (Kirchhoff's law):

$$b_{\lambda T}/\alpha_{\lambda T} = b_{\lambda T}{}^*.$$

$\alpha_{\lambda T}$ is also termed the *monochromatic emissive power*.

450. Colour temperatures

Within the visible spectrum, the emission of a non-black body is equal, or nearly so, to that of a black body at a temperature T_c. This is the *colour temperature* of the body and must not be confused with its *true temperature* T. The black-body at temperature T_c must have the same spectral distribution as the actual source at temperature T.

The colour temperatures of some light sources in increasing order are

Hefner amyl acetate lamp	1875°K
Vernon-Harcourt pentane lamp	1920°K
Paraffin candle	1925°K
English standard candle	1930°K
Melting platinum	2046°K
Paraffin lamp (flat wick)	2050°K
Carbon filament lamp	2080–2130°K
Acetylene lamp (cylindrical flame)	2360°K
Acetylene lamp 'Crescent Aero'	2450°K
Nernst lamp (rare earth oxides)	2400°K
Tungsten filament (vacuum) lamp	2400°K
Gas-filled tungsten lamps	
20·3 lumens/watt	2985°K
24·2 lumens/watt	3175°K
27·3 lumens/watt	3220°K
Electric arc	3780°K
H.I. arc (sun arc)	5500°K
Mean sunlight	5400°K
Sunlight before atmospheric absorption	6500°K
Clear north sky	about 22,000°K

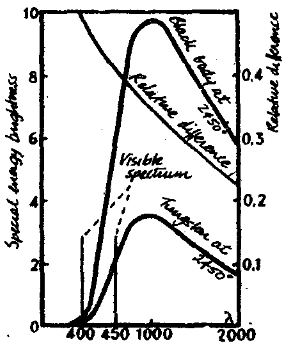

FIG. 58.

The curves in Fig. 58 show the differences existing between the spectral energy brightnesses of tungsten at 2450°K and a black-body at the same temperature. The relationship between the curves shows the variation of emissive power of tungsten with wavelength.

451. Measurement of colour temperature. Thermocolorimeters

The measurement of the colour temperature of the light emitted by a photographic source can be made rapidly using one of several available colour temperature meters.

In principle, the light is analysed by one or more photocells carrying colour filters. The produced current can be amplified, and the colour indicated by a spot on the screen of a cathode ray tube which is marked as a colour triangle. *Neale's apparatus*(4) is of this type and uses three photocells, each with a colour filter and placed in front of a rotating drum shutter.

Harding's apparatus(5) uses a comparison lamp. Others are based on the fact that the colour temperature is given approximately by the ratio of blue to red. One of these instruments, also due to *Harding*, has two selenium cells, carrying, respectively, a blue and a red filter, in opposition on a microammeter; the two cells are alternately covered. The apparatus of Dawson, Grant and Ott(6) passes the blue and red filters alternately in front of the cell. Before this, the light is received on an opal diffuser. We would also mention:

the *Rebikoff thermocolorimeter*;
the *three colour spectrometer* of the Photo Research Corp.,(7) a colour indicator in which the theoretical log relationships of the red/green on the abscissa and the blue/red on the ordinate are considered, the representative points (of a black body) are on a straight line;
the *EEL colour temperature meter* of Evans Electroselenium Ltd., which uses a microammeter, a selenium cell and red and blue filters.

452. Practical light sources

In current practice the light sources used are the incandescent lamp, the carbon arc, the mercury vapour lamp and the metal-filled flashbulb. They emit light of very different spectral composition.

Incandescnt lamp. The efficiency of an incandescent electric lamp, and therefore its emission spectrum, depends on the filament temperature, the filament type and the surrounding gaseous atmosphere.

The *efficiency* (lumens/watts) increases with temperature.

	Type of Lamp		*Colour temperature*	*Luminous efficiency*	*Brightness*
Vacuum:	Carbon filament	(50 W)	2130°K	2·5	55 c/cm²
	Tantalum ,,	(50 W)	2260°K	4·9	53 c/cm²
	Tungsten ,,	(10 W)	2390°K	7·7	128 c/cm²
Gasfilled:	Tungsten filament	(75 W)	2705°K	11.8	560 c/cm²
	,, ,,	(200 W)	2810°K	15·2	780 c/cm²
	,, ,,	(500 W)	2880°K	17·5	1000 c/cm²
	,, ,,	(2000 W)	3000°K	21·5	1350 c/cm²
	,, ,,	(10,000 W)	3300°K	31	3050 c/cm²
	Projector lamp	(1000 W)	3220°K	27·3	2660 c/cm²

To obtain 10 lumens per watt, for example, the colour temperature of a vacuum lamp must be at least 2450°K; with an argon-filled lamp it must be increased to 2800°K whilst with nitrogen, a better conductor, 2900°K must be reached.

Incandescent lamps for studio lighting are obtainable in many different types working on 110–120 V.

200 W	:	1·7 A	2000 W	:	17·4 A
500 W	:	4·4 A	5000 W	:	43·5 A
1000 W	:	8·7 A	10,000 W	:	87 A

Incandescent lamps emit a *yellowish light rich in red rays*: consquently they benefit panchromatic emulsions. Their light becomes whiter as the colour temperature is raised. For colour photographs 3380°K lamps are used together with bluish glass filters.

For indoor pictures, and for some studio effects, *overrun* lamps are used which give a powerful light with a small bulb; Photoflood, Nitraphot, Photolita, Mazdastudia, etc. The colour temperature of these lamps is high, therefore the light is whiter, some of them are blue glass from 250–1000 W with a life of 3–10 hours. With a 500 W 100 hour lamp 11,000 lumens can be obtained. The life of the lamp does not exceed 2 hours if 16,000 lumens are reached by increasing the voltage.

Studio spot lamps have spherical or parabolic reflectors together with lenses. The mirror is silvered glass or chromium plated metal; the former reflects 82–95%, whilst the latter reflects only 62–70%. With steel, 59% is reflected.

453. Carbon arc

The carbon arc is used for studio lighting and for film projection. The light is normally centred on the crater of the positive carbon. Its colour temperature, which is at least 3780°K, depends on many factors: type of carbons, shape of crater, length of the arc, current density, gaseous atmosphere, etc. When the carbons contain metallic salts which change the colour of the light produced, this occurs primarily in the arc itself, between the two carbons.

The light of the arc is much whiter than that of an incandescent lamp because of the higher colour temperature; it is rich in violet rays. It does not affect photographic emulsions in the same way as ordinary electric light; as with daylight, the densities obtained with panchromatic emulsions are lower than when electric light is used.

The carbons containing mineral salts (of cerium or copper) give bluer light, approaching by this means daylight. In addition, at a pressure of 5 atm., a colour temperature of 4460°K can be reached, whilst at 25 atm. 6000°K can be achieved.

Studio spotlight arcs work at 38–150 A at 35–67 V. They are equipped with mirrors or combinations of mirrors and Fresnel lenses. The diameter of the carbons is from 6 to 16 mm depending on the intensity.

Stable arcs can have a power up to 200 kW if they are cooled by circulating