The Illuminant in the Prevention and Phototherapy of Hyperbilirubinemia

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LIGHT IS known to promote many chemical events other than those resulting in vision—the primary concern of the illuminating engineer. The literature is replete with examples of photochemical phenomena ranging from degradation or fading of organic and inorganic dyes, pigments and other materials to synthesis of industrial chemicals and sustenance of life itself.[1-10] Generally speaking, these are of peripheral interest to the illuminating engineer by definition.

The instant case involving the first light to which newborn babies are exposed is, however, an exception for it requires proper illumination of hospital nurseries from both the standpoint of the illuminating engineer and the medical phototherapist whose respective requirements may conflict.[12-16] Superimposed upon the basic conflict—which does in fact exist—is a failure on the part of both to understand the others' jargon.

The purpose of the present paper is to review the elements leading to the conflict and misunderstanding and to put them in a perspective more amenable to scientific evaluation. At the same time, it provides both disciplines with essential illuminant data in accurate tabular form, allowing convenient interconversion between the various systems of units involving illuminance in footcandles (lux), irradiance in microwatts per square centimeter, and quantum densities in quanta per second per square centimeter.

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Hyperbilirubinemia

Hyperbilirubinemia means too much bilirubin in the blood. Bilirubin is formed from the hemoglobin of red cells (erythrocytes) in the course of their normal breakdown and is normally excreted after first undergoing chemical reaction in the liver. When the latter is not fully functional in this respect—as occurs in the first few days of an infant's life, especially premature infants—the bilirubin level can rise in the blood serum and lead to jaundice, which is distinguished by a visually detectable yellow coloration of the skin. If allowed to persist at high levels in the blood, the bilirubin can also cross the blood-brain barrier (penetrable only by fat soluble substances) and stain the brain cells with resulting permanent neurological damage.

The condition is known as kernicterus and results in various degrees of motor and mental retardation. As might be expected, the serum bilirubin level at which this occurs is not sharply defined. Some doctors consider the risk minimal below a concentration of 20 milligrams per 100 milliliters (mg-per cent) of serum and others below 15 mg-per cent and lower.[17-21]

In severe cases, a complete blood exchange is resorted to which is not completely without risk. The expected mortality in this procedure is near one per cent for full-term infants and four per cent for prematures, according to McKay.[18] The incidence of hyperbilirubinemia associated with prematurity is sufficiently widespread (about 10-20 per cent of prematures may be so afflicted[17]) to be of general con-

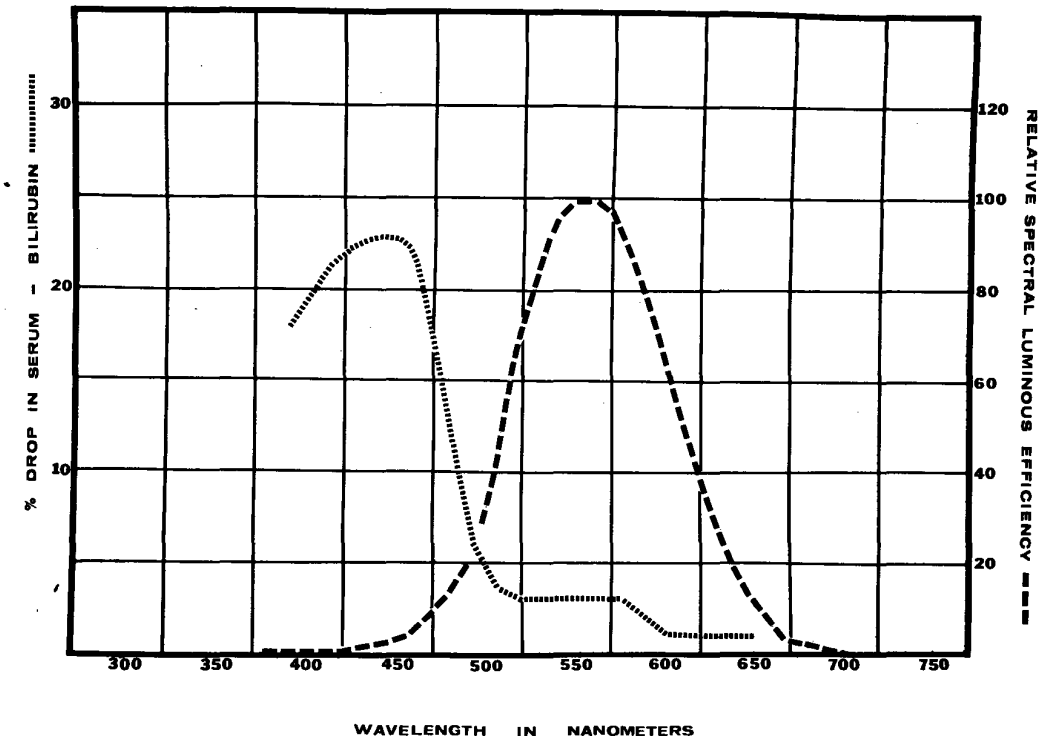

Figure 1. Wavelength dependency for the photodegradation of serum bilirubin (after Cremer) and for the visual brightness sensation (CIE 1931 Standard Observer).

cern, especially in the context of those marginal cases in which damage may be done at lower levels than those generally considered harmful. However, this high incidence is disputed by Gellis.[21]

Phototherapy of Hyperbilirubinemia

The remarkable thing is that bilirubin can be "bleached" by light[19] much like the rhodopsin in the retinal rod receptors. Unlike rhodopsin, however, the bilirubin reaction to light is apparently neither photoreversible nor chemically-reversible in the dark. This is fortunate since it turns out that the photoproducts of bilirubin are apparently excretable. Further, they are apparently incapable of crossing the blood-brain barrier, being water soluble, and are also apparently non-toxic. "Apparently" is properly descriptive since to this present date the real facts have not as yet been incontrovertibly established.[20]

As might be imagined, the discovery of the bilirubin photoeffect has been followed by intensive clinical[17, 22-47] and experimental[38, 44, 48-62] study in many countries reminiscent of the activity following the discovery of the "vitamin D factor" in sunlight early in this century with the attendant array of new lamps and therapeutic devices. Most of the bilirubin clinical work has followed the basic lighting protocol described originally by Cremer.[19] He used a hemispheric stainless steel reflector fitted with eight 24-inch light-blue (presumably 20-watt though 40-watt is stated) fluorescent lamps positioned above the naked infant, who was exposed to the entire visible and ultraviolet spectrum of the lamps. However, while still others have used the same basic geometry, they report using various other colors of fluorescent lamps in their clinical and experimental studies such as blue,[25, 26, 32, 38, 40, 47] cool white,[13, 38, 57] daylight, [17, 30, 31, 32, 34, 37, 40, 43] and special narrow-band blue,[40] as well as natural sunlight,[19, 48] and a lamp simulating CIE D-5500°K with a color rendering index of 91 representing natural sun + sky radiation.[40, 59] Thus, the question naturally arises as to the relative effectiveness of these spectra in the phototherapy of hyperbilirubinemia as well as to what irradiance or footcandle level to use.

Action Spectrum for Phototherapy of Hyperbilirubinemia

The illuminating engineer has no problem in rating light sources for spectral luminous efficiency. Given the spectral distribution of power, he simply has to apply the CIE 1931 Standard Observer function to find the luminosity factor which, when multiplied by the electrical equivalent of light, gives the spectrum

lumens per watt.[63] On this basis the cool white spectrum is the most efficient of the lamps mentioned. The CIE Standard Observer function is the "action" spectrum the engineer needs to rate the effectiveness for generating "light"—light by his definition being the visually evaluated brightness attribute of radiation.

Literature reveals many absorbtion spectra of bilirubin in various media, together with the effects upon the absorption spectrum of *pH* and of irradiation by different light sources for various periods of time.[38, 44, 48, 49, 51, 52] However, the only data corresponding to an action spectrum for photodegradation of serum bilirubin are reported by Cremer.[19]

Absorption spectrum of bilirubin and action spectrum for photodegradation are, of course, not necessarily equivalent. No true action spectrum for phototherapy of hyperbilirubinemia could be found, although Ostrow[55] concludes photodegradation of bilirubin is essentially independent of wavelength between about 400 nm and 600 nm. Cremer does not specify for his data either the initial concentration of bilirubin which is important, the value of the light dosage used, or whether that dosage was based on equal irradiances or equal quantum densities for the different wavelengths shown. It is assumed, however, that the study was done using equal irradiances.

Quantum density may have more significance in photochemical studies of bilirubin since the primary processes are of a quantum nature governed by the Stark-Einstein law.[64] For example, if all wavelengths between 400-600 nm were equally effective on a quantum basis in photodegrading bilirubin, the required irradiance in the blue at 400 nm would have to be 6/4 or 150 per cent higher than for the red at 600 nm, since the blue quantum is that much more energetic than the red.

The action spectra for photodestruction of serum bilirubin (after Cremer) and for the production of the sensation of brightness are compared in Fig. 1. From this, it is evident that radiation near 555 nm in the yellow-green is most effective for producing "light," while that near 410-460 nm in the violet and blue is most effective for "bleaching or degrading" serum bilirubin, which results in the basic difference in "light" requirements of the engineer and the phototherapist. From these curves it is possible to evaluate the relative effectiveness of light sources for which the spectral distribution of power or irradiance is known.

Illuminant Spectral Data and Relative Spectrum Efficiency for Different Action Spectra

Spectral data for standard fluorescent lamps are quite uniform among various manufacturers.[65] Tables I and II provide spectral characteristics for illu-

Table I—Spectral Irradiance Distribution of Light Sources Used in Prevention and Therapy of Hyperbilirubinemia.

(Microwatts per square centimeter per footcandle)

Wavelength (nm.)	CIE D-5500°K*	Cool White	Daylight	Blue	Blue-White	CIE D-5500°K CRI 91
770	.114	.004	.004	.002	.003	.013
760	.079	.004	.004	.002	.003	.017
750	.108	.005	.005	.004	.004	.022
740	.128	.005	.005	.003	.005	.027
730	.119	.006	.006	.004	.005	.034
720	.105	.008	.007	.004	.007	.042
710	.127	.010	.009	.005	.008	.052
700	.124	.012	.011	.005	.009	.062
690	.120	.017	.015	.009	.013	.074
680	.135	.020	.018	.009	.014	.085
670	.141	.027	.024	.010	.017	.097
660	.136	.036	.031	.013	.021	.108
650	.133	.050	.041	.015	.026	.119
640	.139	.066	.054	.020	.032	.127
630	.136	.088	.072	.023	.039	.135
620	.141	.114	.092	.029	.047	.138
610	.143	.144	.115	.035	.057	.139
600	.142	.173	.140	.045	.067	.138
590	.137	.198	.158	.054	.082	.136
580	.147	.243	.211	.153	.127	.170
570	.146	.207	.177	.093	.119	.131
560	.150	.176	.161	.102	.129	.131
550	.155	.194	.200	.237	.216	.185
540	.153	.145	.165	.225	.211	.191
530	.156	.089	.119	.179	.187	.146
520	.150	.078	.119	.212	.204	.145
510	.151	.075	.123	.251	.225	.135
500	.151	.078	.133	.296	.234	.127
490	.147	.080	.139	.337	.253	.125
480	.154	.081	.142	.383	.252	.124
470	.150	.081	.141	.419	.251	.119
460	.151	.075	.136	.454	.233	.112
450	.147	.077	.123	.469	.212	.103
440	.128	.161	.219	.693	.319	.202
430	.102	.124	.175	.629	.250	.189
420	.107	.044	.080	.451	.115	.062
410	.103	.067	.098	.407	.132	.093
400	.092	.060	.079	.417	.102	.080
390	.057	.022	.030	.261	.037	.031
380	.049	.012	.017	.187	.020	.025
370	.052	.009	.013	.129	.026	.050
360	.046	.006	.007	.074	.020	.057
350	.042	.001	.002	.044	.001	.039
340	.036	.0002	.0004	.013	.001	.031
330	.031	.0004	.0004	.007	.001	.017
320	.017	.006	.004	.007	.004	.004
310	.003	.014	.010	.017	.010	.019
300	0	.004	.001	0	.0002	.0004
290	0	.001	.0002	0	0	.0004

* Representing natural sun plus sky radiation at a correlated color temperature of 5500°K.

Table II—Spectral Quantum Density Distribution of Light Sources Used in Prevention and Therapy of Hyperbilirubinemia.

(Quanta per second per square centimeter per footcandle). (Multiply all values by 10^{12})

Wavelength (nm.)	CIE D-5500°K*	Cool White	Daylight	Blue	Blue-White	CIE D-5500°K CRI 91
770	.442	.015	.014	.008	.010	.052
760	.304	.016	.015	.009	.012	.066
750	.407	.019	.019	.013	.015	.082
740	.474	.020	.020	.013	.017	.102
730	.438	.024	.021	.014	.019	.125
720	.382	.028	.027	.015	.024	.153
710	.455	.035	.033	.017	.030	.185
700	.438	.041	.040	.018	.032	.218
690	.415	.058	.051	.030	.044	.258
680	.463	.070	.062	.030	.048	.292
670	.475	.091	.082	.034	.059	.326
660	.450	.120	.105	.042	.070	.359
650	.436	.162	.134	.050	.084	.389
640	.447	.214	.176	.064	.102	.411
630	.431	.279	.228	.074	.123	.428
620	.442	.358	.287	.090	.146	.431
610	.438	.443	.353	.108	.174	.428
600	.428	.523	.423	.135	.204	.418
590	.407	.587	.470	.160	.243	.404
580	.428	.707	.614	.447	.372	.495
570	.418	.594	.506	.268	.341	.375
560	.423	.497	.452	.286	.363	.369
550	.428	.539	.553	.656	.598	.511
540	.416	.394	.450	.612	.574	.520
530	.417	.238	.316	.478	.499	.389
520	.393	.204	.311	.554	.534	.379
510	.388	.192	.316	.643	.577	.347
500	.381	.196	.336	.746	.589	.321
490	.362	.197	.342	.833	.615	.309
480	.372	.197	.342	.925	.609	.300
470	.354	.191	.332	.990	.593	.281
460	.349	.174	.315	1.050	.540	.260
450	.333	.175	.278	1.060	.480	.233
440	.284	.356	.484	1.534	.706	.447
430	.221	.269	.378	1.362	.540	.409
420	.227	.093	.169	.953	.242	.131
410	.212	.138	.201	.840	.273	.192
400	.184	.120	.159	.838	.205	.161
390	.113	.044	.059	.512	.072	.061
380	.094	.024	.032	.357	.038	.048
370	.096	.017	.024	.241	.048	.092
360	.083	.011	.013	.135	.036	.103
350	.074	.002	.003	.077	.002	.069
340	.062	.0004	.001	.022	.002	.053
330	.052	.001	.001	.011	.001	.028
320	.027	.009	.006	.010	.006	.006
310	.005	.023	.016	.027	.015	.029
300	0	.006	.001	0	.0004	.0004
290	0	.001	.0004	0	0	.0004

* Representing natural sun plus sky radiation at a correlated color temperature of 5500°K.

minants, including natural light used in bilirubin phototherapy to date. Data are expressed in microwatts per square centimeter per 10 nanometers per footcandle (10.76 lux) in Table I, and quanta per second per square centimeter per 10 nanometers per footcandle in Table II. Mercury lines are included in the 10 nanometer band in which they fall, or where borderline they are divided equally between adjacent bands. These data thus allow interconversion at any wavelength between footcandles, irradiance and quantum density. For total spectrum conversion, Table III conveniently lists the factors for converting measured footcandles to irradiance and quantum density for each of the sources.

By weighting the spectra of Table I (normalized to equal irradiance and not irradiance per footcandle) by the curves of Fig. 1, the relative effectiveness of the various spectra in producing "light," or the theoretical relative effectiveness in photodegrading bilirubin can be computed, and the results of such computations are shown in Table IV. It is apparent from this table that the illuminating engineer would be tempted to select cool white fluorescent lamps from the lamp group to maximize lumen output, while the phototherapist would be tempted to choose blue lamps to maximize bilirubin destruction. But there are other factors which should be considered before a final selection in either case is made.

Other Considerations

By using the action spectrum for producing the sensation of brightness (Fig. 1) as the sole criterion for illuminant selection, the engineer makes a grave error since this would ultimately lead him to use illuminants richest in green radiation. The green 40T12 fluorescent lamp, for example, produces 4300 lumens compared to 3110 lumens for the cool white lamp.[66] The reason the engineer rejects the green lamp is obvious—color. This simply means, however, that he first rejects the fundamental action spectrum proposed as the criterion for lamp spectral design in favor of other considerations; in this case, the lamp color and color rendering index.[67] A similar (even identical regarding color discrimination!) argument can be made against the use of blue lamps in the prevention and phototherapy of hyperbilirubinemia *provided*, of course, that any alternative selection performs adequately in photodegrading bilirubin. The importance of color and color discrimination for *general* nursery illumination[11-12] and for *prevention* of hyperbilirubinemia[13,14,33] is obvious, but it is considered equally important by others even for localized phototherapy units.[30,32] In view of this, a sensible compromise would seem to be to use a wider spectrum source of high color rendering index with substantial output in

Table III—Conversion Factors for Light Source Spectra: Footcandles/Irradiance and Quantum Density.

(For λ = 290-770 nm)

Multiply footcandles of}	CIE D-5500°K (sun + sky)	Cool White	Daylight	Blue (Calcium Tungstate)	Light Blue (Magnesium Tungstate)	CIE D-5500°K CRI 91
To obtain ↓ By ↘						
Irradiance in μwatts/cm^2	5.38	3.20	3.63	7.44	4.35	4.41
Quantum Density in Quanta/sec.cm^2	15.37 x 10^{12}	8.71 x 10^{12}	9.57 x 10^{12}	17.39 x 10^{12}	10.93 x 10^{12}	12.05 x 10^{12}

Table IV—Relative Theoretical Effectiveness of Various Light Source Spectra for Photodegrading Serum Bilirubin in a Test Tube and for Producing the Sensation of Brightness.

Spectrum	Relative Theoretical Effectiveness Based on Equal Total Irradiances between 290 nm. and 770 nm. *Photodegradation of Serum Bilirubin *In Vitro*	Production of Sensation of Brightness
CIE D-5500°K (sun + sky)	100	100
Fluorescent Lamps:		
Cool White	121	168
Daylight	152	148
Blue (calcium tungstate)	244	72
Light Blue (magnesium tungstate	179	124
CIE D-5500°K (CRI 91)	120	122
Monochromatic Violet (λ = 440 nm.)	400	7.9
Special Narrow-band Blue**	380	10.9

* Assuming Fig. 4 of Cremer[19] is based on equal irradiance dosages as opposed to equal quantum dosages.
** Values estimated from reference 40 which roughly compares this lamp with standard blue and other colors.

the blue range. There are, however, still more compelling considerations.

Biologic Effects of Light

Photochemistry of Serum Bilirubin

Photodegradation (whether photodissociation, photooxidation, etc.) of bilirubin is just one of many known effects of light upon mammals, including humans. Even in the case of the effect of light on bilirubin, however, the picture has been greatly oversimplified thus far in the present report. For example, Cremer[19] and Broughton[41] postulate that the great variation in response to light therapy between individuals may be due to the absence or presence in varying amounts of different substances which can affect bilirubin through photodynamic action—specific mention being made of riboflavin. Such substances, if present, could change the action spectrum for bilirubin photodegradation and could conceivably account for the conflicting statements about the effectiveness of near-ultraviolet radiation (around 365 nm) in degrading bilirubin. Sisson,[40] Ostrow[55] and Lucey[17] state it is effective while Ballabriga[50] reports the opposite.

The absorbance spectrum of icteric serum is known to progressively shift from the broad peak around 460 nm to a peak at 410-415 nm with increasing light dosage.[19, 38, 48, 51, 52] Additionally, new peaks occur in the near-ultraviolet and in the red end of the spectrum. What is the effect of simultaneous light irradiation into these bands? Blondheim[48] as well as Ansaldi[52] associate a 415 nm peak with free bilirubin (or other pigment associated however with kernicterus) and a 460 nm peak with bilirubin bound to albumin (and therefore unable to cross the blood-brain barrier). However, Ostrow[68] attributes the 415 nm peak to an artifactual composite. Is it important that the illuminant used in phototherapy have radiation at 410 nm as well as 460 nm?; also at 365 nm (or 350 nm) and 660 nm? The latter peaks are found after continued light exposure or serum bilirubin. The answers to these and many other questions specifically involving photoeffects on jaundiced serum may be a long way off.

Table V—Some Particulars of Various Studies on the Phototherapy of Hyperbilirubinemia.

STUDY		LIGHTING PROTOCOL					IRRADIANCE		PHOTOPERIOD			DOSAGE		
(CLINICAL)												ACTUAL		THEOR.[k] Effective
Ref.	Infants Treated	Source	No. Lamps	Reflector	Distance (cm.)	Ft.cd.	290-770nm mw/cm²	290-380nm μw/cm² **	Hrs. per day Total	Periodicity On	Off	290-770nm mw-hrs. cm²	290-380nm mw-hrs. cm² **	290-770nm
19	13	Sunlight[a]	-	-	-	5000*	27	1260	2.5[b]	.3	.3	67	3.2	17
19	7	20w. Blue-White	8	Stainless Steel	75*	240*	1.0	18	18	6	2	19	.3	8
13	47	75w. Cool White	m	Enamel	122	90	0.3	4	24	Continuous		7	.1	2
22	15	20w. ?	8	Metal	-	-	-	-	24	Continuous		Pigmentation due to uv reported		
24	28	20w. Blue[c]	10	-	40	-	-	-	18	6	2	-	-	-
25	55	? Blue	8	Metal	40	-	-	-	24	Continuous		-	-	-
26	38	20w. Blue	10	White Paint	35	(23[d])	(0.2)	(9)	24	Continuous		(4)	(.2)	(2)
28	15	40w. ?	5	Aluminum	40	-	-	-	6	Alt. Days		-	-	-
29	11	40w. Blue-White	8	Stainless Steel	75*	300*	1.3	22	18	6	2	24	.4	11
30	10	20w. Daylight[e]	9	Aluminum	50	214	0.8	10	18	6	2	14	.2	5
31	14	40w. Blue	8	-	100	150*	1.1	58	18	6	2	20	1.0	12
32	14	40w. Daylight[g]	8	Aluminum	40	(2300[f])	(8)	(108)	24	Continuous		(200)	(2.6)	(76)
34	76	20w. Daylight	8	Polished Aluminum	40*	300*	1.	14	24	Continuous		26	.3	10
35	1[h]	40w. Blue	8	-	100	150*	1.1	58	18	6	2	20	1.0	12
36	53	20w. Daylight	10	j	-	500*	2.	(24)	24	Continuous		44	(.6)	17
37	50	20w. Daylight	10	j	-	500*	2.	(24)	24	Continuous		44	(.6)	17
38	183	40w. Blue	8	-	80	130*	1.0	50	18	6	2	18	.9	11
39	28	40w. Blue	i		40				18	6	2			
40	37	20w. Blue	10	j	-	300	2.2	(115)	24	Continuous		50	(2.8)	31
43	23	20w. Daylight	10	-	-	450	1.6	21	24	Continuous		39	.5	15
46	1[h]	20w. Daylight	11	j	60	500*	1.8	(24)	24	Continuous		44	(.6)	17
47	1[h]	40w. Blue	8		45	350	2.6	134	24	Continuous		66	3.2	38
EXPERIMENTAL														
59	(rats)	20w. Blue	6	Aluminum	75	90	.7	35	8	8	16	5.4	.3	3.3
59	(rats)	20w. Daylight	6	Aluminum	75	220	.8	10	8	8	16	6.4	.1	2.4
59	(rats)	20w. D-5500	8	Enamel[j]	75	150	.7	(35)	8	8	16	5.3	(.3)	1.6

NOTES: *Assumed or estimated from best available data. **No correction for reflector material.

a. Assume CIE D-5500°K (footcandle level is believed estimated low).
b. 15-20 minute exposure followed by equal dark period.
c. States emission between 420-480 nm.
d. Apparent error. ( ) indicates highly doubtful values.
e. Differs from standard daylight in having better color rendering and therefore lower lumens per watt. Irradiance and dosage based on standard light.
f. Reports 2300 lumens; assume footcandles (this appears an order of magnitude too high, however).
g. Apparently same lamp spectrum as reference 30.
h. Crigler-Najjar Syndrome.
i. 6.2 cm. apart but number not given.
j. UV absorbing plastic filter of unspecified wavelength cut-off between lamps and infants.
k. Weighted for relative theoretical effectiveness in photodissociating serum bilirubin [$\lambda 440_{nm.} = 100$ (cf. Table IV)]
m. General nursery illumination.

A survey of the literature shows variable results regarding *in vivo* and *in vitro* studies of the per cent reduction of bilirubin in jaundiced serum. Differences may be attributable to total irradiation dosage (intensity × time) and spectral characteristics of the illuminants used, in addition to many other factors, some of which have already been mentioned. Some of the essential features of the various studies are shown in Table V, in which an attempt was made to reduce the light protocol used to at least equivalent terminology through the use of data presented in Table I. It is evident that treatments have varied widely respecting actual dosage, theoretically effective dosage, spectral distribution, and presence or absence of ultraviolet. Regarding the latter, it is noteworthy that variations ranged from none, to dosages which must have been almost erythemal (Cremer[19] placed naked infants in full sunshine for 20-minute intervals for periods up to three hours in a single day without any reported harmful effects!).

Can Light Be Harmful?

This is a serious consideration. Obviously, light or any other radiation can be harmful to life when delivered in sufficiently high irradiances even for short periods of time, *e.g.*, witness radiant damage from nuclear explosions or laser beams. Or where the effect is cumulative, lower irradiances for longer periods of time may be harmful as from X-radiation. As everyone knows, sunlight can deliver painful burns to the unwary and untanned!

But if the above were the extent of possible harmful effects of light, the matter could be quickly brought to an end regarding any danger from exposure of thousands of infants (as the practice has now become) to mere fractions (less than 1/10 or 1/20) of the light *intensities* enjoyed by everyone stepping out-of-doors on a daily basis since man arrived! (When comparing *dosages*, the fractions may be larger depending on the hours of phototherapy administered per day.) The fact is that there may be a matter of concern even at relatively low levels of lighting.

Such is suggested by recent studies[43, 59, 69-77] on both animals and people. The net thrust of these studies leads toward a seemingly obvious conclusion: *light* is a true environmental factor as much as or even more than air, water or temperature! Attempts to change it from the natural, either compositionally or to drastically modify the portion delivered to a living system, can logically be expected to have some effect. What effects remain to be seen. Obviously, the matter needs the concerted attention of the illuminating engineer, the lamp industry, the photobiologist, and the medical profession.

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DISCUSSION

E. D. BICKFORD:* The authors have presented a valuable review of past and current literature on the phototherapy of a serious pathological condition in infants, hyperbilirubinemia. They also have presented useful information on the spectral energy and quantum emission from fluorescent lamps which

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have been used in the phototherapy of this condition, and have offered the means for using a footcandle meter to determine the energy and quanta from these lamps in limited spectral regions.

As the authors have adequately pointed out, there are many questions yet to be answered on the phototherapy of bilirubin. Therefore, I will try to limit by comments and questions to the content of the paper.

In the data presented in Table IV, the authors have evaluated light sources based upon the work of Cremer (1958) rather than on the more recent work of Ostrow (1970). Even though the authors were critical of the data presented by Cremer, they apparently felt that the work of Cremer was more valid, accurate, or credible than the work of Ostrow. Is this an accurate assumption? If so, how and why was the decision made to use one work over the other?

If the work and conclusion of Ostrow is valid and the photodegradation of bilirubin is essentially independent of wavelength between about 400 and 600 nm, then the relative effectiveness of fluorescent lamps in Table IV would be quite different than as presented. In addition, it would relieve, to a great extent, the dilemma and confusion of choosing a lamp with an emission in the blue spectral region over a lamp emitting throughout the visible region. Simple calculations from Table I and II based upon Ostrow's conclusion shows that of the three white fluorescent lamps, the daylight lamps would emit the greatest energy and number of quanta in the 400 to 600 nm region followed by cool white and the CIE D-5500°K CR191 lamps. The daylight lamp would also emit more energy and quanta per lamp than the standard blue fluorescent lamp, and in addition would serve as a relatively good illuminant for monitoring skin color of a jaundiced infant. For color discrimination, the daylight lamp would be the intercediate illuminant, *i.e.*, better than cool white but not as good as the CIE D-5500°K CR191 lamp. Without some kind of study, it would be difficult to predict the need, value or preference for an illuminant to best determine changes in skin color of a jaundiced infant. Perhaps a simple optical device could be developed and utilized in incubators to monitor skin color changes, thus utilizing the most effective light source to alleviate the condition without concern for its specific color rendering value. Obviously, the light source chosen for phototherapy of hyperbilirubinemia should be based upon clinical evidence which demonstrates that it is the most effective therapeutic device for alleviating the condition without producing harmful side effects. Consideration of the light source as an illuminant should likely be discounted in favor of such evidence. Although it was not indicated in the table heading, it is assumed that the conversion factors in Table III are for the same wavelength region as in Table I and II, *i.e.*, 290 through 770 nm. If a *different wavelength region were used, the conversion factors* could be very different from those presented.

In the interest of accuracy in measurement, there is some caution to be observed in the utilization of the footcandle meter and the conversion factors in Table I, II and III. The information presented in these tables assumes that all footcandle meters are identical in watching the CIE luminosity curve, and that there are no variations in the spectral energy distribution in life or from manufacturing variations for all the lamps listed. Such an assumption can lead to errors, especially if exact energy levels are desired for a specific research study. However, the use of these conversion factors results in greatly increased accuracy over methods which have been used and which compare light sources with widely divergent spectral energy distributions on an equal footcandle level.

Natural daylight has been considered by biologists for many years as an important and potent environmental factor. (Perhaps engineers, including illuminating engineers, have more recently become aware of this phenomenon.) Although man and all other living organisms are completely dependent upon it and it has prevailed throughout man's evolution, natural daylight should not be accepted with apathy as a harmless source of light. The reasoning that, "because sunlight or daylight is natural light, its full energy and spectral output are harmless and good for human beings," is scientifically and medically unfounded. For example, there is such clinical evidence as the near and complete loss of vision during last year's eclipse, annual cases of eye damage, and sunblindness, including those cases requiring hospitalization from severe sunburn, sunstroke, skin tumors, skin cancer, and skin allergies. Skin cancer is the most frequent cancer of man, correlating directly with the amount of sunlight exposure and attributed to the spectral region from 290 to 320 nm.

In regard to the change in spectral composition, natural daylight is phenomenal in this regard. For example, the color temperature for daylight varies from about 3500°K to 45,000°K, and the spectral emission of daylight varies from a peak emission at about 470 nm at noon to a peak emission at about 670 nm near sunset.

If there are extra visual effects of spectral energy in the visible region (380 to 760 nm), it seems that we must not only learn what effects are associated with energy in specific spectral regions applied independently and/or simultaneously, but also learn the effects of changes in energy and wavelength. All of these variables would supply a considerable number of experimental possibilities.

J. W. SAUSVILLE:* It has been our pleasure to cooperate with Dr. Sisson and his associates at Temple University (cf. authors' refs. 40, 58, 71) by supplying experimental lamps with narrow spectral power distributions. These lamps have been used to measure the effective action spectrum of the photodegradation by bilirubin *in vitro* and *in vivo*. From this association and from other contacts in the field of phototherapy, we have reached several conclusions worthy of note here.

First, the medical practitioner knows far too little about the lamps he uses—their emissive qualities, their effective lifetimes and the optimum conditions for their use. Secondly, the phototherapist frequently does not have instruments for measuring the spectral quality or the output of lamps which he uses. Thirdly, considering the dearth of knowledge on the effect(s) of spectral quality and intensity of light on the human system, the practitioner should apply phototherapy to his patients on a strictly individual basis. If undesirable side effects of phototherapeutically beneficial illumination do indeed exist, such illumination should be used in the same manner as any drug which has a finite probability of causing undesirable side effects.

This latter consideration suggests rejection of the authors' "sensible compromise" for the illuminant in localized phototherapy units, namely "a wider spectrum source of high color rendering index with substantial output in the blue range."

*Westinghouse Lamp Division, Bloomfield, N. J.

For, if an illuminant emitting blue radiation in a narrow band peaking at 445 nm reduces dangerous bilirubin levels in an infant to tolerable levels in one-half or one-third the time which would be required using a broad spectral emitter, the logical choice of illuminant is obvious.

With respect to potential side effects of the phototherapy of hyperbilirubinemia, it is encouraging to learn that Dr. Ballowitz in repeating her experiments (authors' reference 59) with Gunn rats using refined control conditions, observed no deleterious effects attributable to the phototherapy.*

SYLVESTER K. GUTH:** The authors seem to have done their homework. At least they have appended to their paper an impressive list of references. However, it is evident that among the cited literature there seems to be considerable divergence of result and opinion on many aspects of phototherapy for treating hyperbilirubinemia in terms of energy level, exposure time and spectral distribution.

This brings up a very important point: decisions on these, and indeed on any aspect of phototherapy, must be made by the medical profession. They are outside the province of the illuminating engineer. We, therefore, must be very careful that we do not make recommendations regarding phototherapy. We have no business making claims for beneficial or harmful effects of radiant energy, except with respect to those aspects on which there is complete medical unanimity. But even there care must be exercised in what we say or imply. Our function is to provide the tools—technical information on sources, lighting techniques, measurements—for the medical people who must make the final decisions and recommendations.

All of this points up some problems in evaluating various experimental results. As is indicated in the authors' Table V, spectral distribution and energy levels often are inadequately described. Not included in the table are results obtained with 80 to 100 footcandles from incandescent lamps which also have been found effective. With such great divergences in dosages, how can one reach any definite conclusions regarding the most appropriate source to use?

I am in complete agreement with the authors' final statement that the matter needs the concerted attention of the illuminating engineer, the lamp industry, the photobiologist and the medical profession. Recognizing the importance of *all* photobiological effects, the IES has established an RQQ Subcommittee to deal with this. By including representatives from all the interested groups, this subcommittee will be in a position to fulfill its basic charter: evaluate and interpret data and other information on the biological effects of radiant energy; advise the IES on matters pertaining to these effects; and recommend projects which might be sponsored (at least in part) by the IERI. In addition, we will be prepared to provide technical guidance on sources, measurements and lighting techniques for the researchers.

*Private communication.
**General Electric Co., Nela Park, Cleveland, Ohio.

LUKE THORINGTON, L. CUNNINGHAM, J. PARASCANDOLA:* The authors thank Messrs. Bickford, Sausville, and Guth for their commentaries and constructive questioning and will reply to these in the order given.

Dr. Bickford questions the use of Cremer's data over the more recent Ostrow data on the spectral dependence of the photodegradation of bilirubin. The answer lies in the fact that Cremer worked with icteric (jaundiced) serum while Ostrow worked with artificial bilirubin solutions. Thus Cremer's data are closer to the *in vivo* reaction than Ostrow's, which is purely experimental. Obviously, if and when we have accurate data for the spectral dependence of the *phototherapy* of jaundice, it will be possible to match the light source to the action spectrum—if this is desirable. As has been pointed out, it is not always desirable to do this; witness the visual brightness function or the erythemic function. Matching the first leads to green-yellow light for best illumination, and matching the latter leads to unhealthy skin reddening without real tanning. Surprisingly, both action spectra have fooled lamp companies into making lamps designed to maximize each response! The authors disagree with Dr. Bickford regarding the best illuminant for discrimination on skin color. There is little uncertainty that high color temperature (5000-7500°K) high color rendering sources are desirable since the color range is from blue (cyanosis) to yellow (jaundice) and variations in red (anemia). Dr. Bickford is right when he says "the light source chosen for phototherapy . . . should be based upon clinical evidence." The point is that by the time such evidence is available at least one generation will have passed while in the meantime thousands of infants will have been treated with a wide variety of sources having possible unknown effects upon them. The authors feel that the answer for this interim period is to use light which simulates the natural phenomenon.

The same wavelength range was used for Tables I, II and III as surmised by Mr. Bickford, and will be so indicated on the final copy. It is of course true that footcandle meters themselves are quite variable as to spectral sensitivity and care must be taken in using erroneous footcandle readings and converting to irradiance and quantum density values—these may be in great error depending on the source and degree of mismatch between the spectral response of the meter and the $V\lambda$ brightness function.

Just as Mr. Bickford cites blindness resulting from looking into the sun, and hospitalization and possible skin tumors and cancer from overexposure to the sun as pointing up certain dangers associated with natural light, so also can one cite drowning and compressed air illness from too much water or too much air. Certainly everything in nature is not good; there are catastrophies and calamities on every hand. However, there are certain *environmental* factors such as air, water, light and temperature which are reoognized as necessary to sustain life as we know it. These by definition are good, and contrary to Mr. Bickford, natural light it not as variable as he states. It is true that the setting sun may be red, and the clear north sky blue, giving the wide range of color temperature he cites, but the light falling on the earth's surface (global radiation) is surprisingly constant in color temperature and ranges from a low of about 5500 kelvins to about 6800 kelvins.[1] It is this radiation which has given birth to life, and sustains it. The individual components of this light—the red to white sun, the gray to blue sky—blend to give the relatively narrow range of global radiation at the earth's surface.

*Authors.

The authors can readily agree with Mr. Sausville's three conclusions. However, it should be noted that the practitioner (third conclusion) has little real photobiologic information to guide him in applying phototherapy on a "strictly individual basis." What is he to do until such knowledge becomes available? Again, the authors feel that light most closely simulating the environmental natural light is the logical choice. This light has been photodegrading bilirubin in both infants and adults from the beginning of man. It is a simple matter to adjust illumination levels to achieve the required rate of bilirubin degradation. Regarding possible side effects caused by narrow band blue sources Mr. Sausville notes additional experimental data from Dr. Ballowitz. To this must be added the report by Dr. Fiske[2] of definite growth retardation in animals under blue light as compared with red or white light sources.

Without question, as Dr. Guth points out, medical decisions must be made by the medical profession. However, an uninformed medical profession cannot make correct decisions and the purpose of the present paper is therefore to inform. Unfortunately, about the only thing many of the profession seem to have known about light is that it is measured in footcandles—indeed if measured at all. This is the fault, in turn, of the illuminating engineering profession which has in the past prescribed footcandle levels without regard to either color temperature or color rendering characteristics of the light sources, leaving the impression that only footcandles are important. This, of course, is wrong and we now have the job of stressing the importance of all wavelengths of photobiologic radiation which is present in the natural spectrum and not just the yellow-green which the footcandle meter unduly emphasizes.

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[1]Gunter Wsyzecki personal communication.
[2]IERI-IES Photobiology Conference, March 30-31, 1970.