Using Norie's ABC Tables:

	Vega	Antares	Regulus
Table A	0·26	0·32	0·03
,, C	0·11	0·83	1·12
,, B	0·37 (Sum)	0·51 (Diff.)	1·09 (Diff.)
Alt.	16¾°	21°	47½°

Using Rapid Navigation Tables:

Col. X	2·64	3·16	0·25
,, Z	1·12	8·31	11·20
,, Y	3·76 (Sum)	5·15 (Diff.)	10·95 (Diff.)
Alt.	17°	21°	47½°

Using *Sight Reduction Tables* (AP 3270):

Vega: Az. 054°, altitude 16° 55′
Antares: Az. 131°, altitude 21° 34′
Regulus: Az. 266°, altitude 47° 46′

Irradiation: A Note

Charles H. Cotter

It is some considerable time since the questions associated with irradiation were considered in the pages of the *Journal*. Indeed the interesting and practical paper[1] by Captain Brett Hilder is the latest considerable contribution to the *Journal* and this appeared no less than twenty years ago. It is only in comparatively recent times that nautical astronomers have been provided with an authoritative irradiation correction of any sort. This, which applies only to observations of the Sun's upper limb, was incorporated in the altitude correction table for the Sun and appeared annually in the *Nautical Almanac* after 1953, the year of Hilder's paper, but was discontinued after 1969.

The introduction of the irradiation correction stemmed from the work of Clemence on atmospheric refraction, some of the results of which were published in 1951.[2] It was Clemence's paper which appears to have prompted Hilder to record his ideas on the subject. Haines and Allen in their paper[3] of 1968 state that most of the experimental evidence to date suggests that the cause of irradiation is 'the scattering of light within the observer's eye'. This it seems produces an increased minimal angle of resolution (MAR), the determination of which Haines and Allen used to quantify the irradiation phenomenon. The implication in their statement is that the cause, or causes, of irradiation are not completely understood.

The earliest reference to irradiation that I have found in a navigational manual is in the sixth edition (I have checked that it is not in the first) of Raper's *Practice*.[4] He makes a very brief mention:

'The effect of irradiation, or the increase of the Sun's apparent diameter, caused by the extreme brightness, and which may amount to 5″ or 6″ (Dr.

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Robinson on Irradiation, *Mem. Roy. Ast. Soc.*, Vol. IV), is removed by observing both limbs.'

Precisely the same comment appears in the most recent edition of Raper's *Practice*, edited by Goodwin and published in 1920.

Staff-Commander Martin, R.N., writing in 1888,[5] makes a reference to irradiation in his description on how a sextant should be used:

'In order to equalize the apparent brilliancy of two objects between which an angle is being measured, the coloured shades should be turned down so as to give as little contrast of *colour* as possible, and the telescope, by means of the up and down piece, screwed in or out from the plane of the instrument until the intensities of light from the two objects are equal.'

In a footnote Martin states that the necessity for doing so arises partly from the fact that the more brilliant of two objects of exactly the same size always appears to be the larger. 'This effect', he wrote, 'is termed irradiation.'

Lecky, in his *Wrinkles*[6] (second edition, 1884), wrote in connection with Sun-sights:

'Beginners are very apt to use too bright Suns, and in consequence the effect known as 'irradiation' *spoils the sharpness of the limbs*. (Italics mine.)

The manuals quoted above were designed to assist seamen in learning practical navigation, but from the time when professional examinations were first set for ship's Masters and mates *manuals* tended to be displaced by *textbooks* designed specifically to assist examinees to pass examinations, and such an interesting and useful item as irradiation (seemingly never considered suitable for the examination room) passed into a state of oblivion not to be resuscitated until the early 1950s.

The irradiation correction ($1'.2$) given in the *Nautical Almanac* was based on the assumption that irradiation of the Sun's upper limb (which tends to give an increased altitude) and that of the horizon (which tends to depress the horizon in excess of the normal dip) are each equal to $0'.6$. On this basis the irradiation of the Sun's lower limb (also assumed to be $0'.6$) neutralizes exactly the irradiation of the horizon so that no irradiation correction is necessary for lower limb observations.

Some navigators are now asking questions similar to those posed by Hilder; and in the light of Dr. Clemence's comments on Hilder's paper:

'. . . It is clearly proper to correct this error . . .; it should be regarded as provisional and subject to modification when we learn more about the subject. . . .'

The questions are: Has further work (such as that by Haines and Allen) on irradiation been done which might warrant a revision of the view that only observations of the Sun's upper limb should be candidates for irradiation correction?' If so, should it be $1'.2$?

Observations of a crescent Moon often provide compelling evidence of irradiation of the Moon (the phenomenon of the 'Old Moon lying in the New Moon's arms' has been observed by almost every seaman) so that it would seem that Moon-sights should also qualify for an irradiation correction. And when the Sun (or Moon) is low in the sky, the horizon is often irradiated *upwards* by the brilliance of the shaft of light on the sea surface; the hump of an excessively irradiated sea horizon under the Sun or Moon is also a phenomenon that must have been observed by almost every seaman.

Another interesting problem links irradiation of the horizon with the dip of the horizon. Did the compilers of dip tables in which terrestrial refraction is incorporated also incorporate, unwittingly, an irradiation factor? The French physicist Biot assumed that the dip of the sea horizon is less by $\frac{1}{13}$ than the dip of the theoretical or 'geometrical' horizon, and this fraction is used as a basis of present-day dip and distance of the sea horizon tables. Other investigators gave fractions as widely divergent as $\frac{1}{4}$ and $\frac{1}{24}$ and perhaps this was as much due to variations in irradiation as it was to the physical character of the atmosphere.

Lastly; if, as we are sometimes informed, irradiation is a physio-psychological phenomenon, how can the problem of irradiation error have a general solution applicable to every observer?

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D. H. Sadler comments:

As Captain Cotter points out, the correction of $-1'.2$ for irradiation in the altitude-correction tables for the upper limb of the Sun was introduced in *The Nautical Almanac* (then titled *The Abridged Nautical Almanac*) for 1953 as a direct result of the work of Dr. G. M. Clemence. There was later some criticism of this action and, for this and other reasons, it was decided, in the spring of 1959, to carry out a programme of special observations planned with the object of confirming, or not, the desirability of retaining the adopted correction for irradiation. The observations were made by members of the staff of H.M. Nautical Almanac Office, under the direction and leadership of Mr. W. A. Scott, who personally made over 2500 observations out of the total of 7820; in addition 668 observations at low altitudes were made at sea by 19 specialist navigation officers at the Royal Navy's navigation school at H.M.S. *Dryad*.

The observations were planned to isolate as far as practicable the differential correction (d) for irradiation between the upper and lower limbs of the Sun. A series of observations consisted of 40 (occasionally 20) alternating measures of the observed altitudes of the upper and lower limbs, giving rise to 20 (occasionally 10) values of d. The sights were taken by one observer, with the sextant readings and times of observation taken and recorded by two assistants; all reasonable precautions against systematic error were taken, and all relevant information recorded.

Unfortunately it proved impracticable to obtain observations at low altitudes from convenient land stations on the south coast; and the observations made by officers at H.M.S. *Dryad* only partially filled this gap. The main observing programme was terminated in the summer of 1960 but discussion was delayed for various reasons—partly in the hope that it would be possible to get an adequate number of low-altitude observations for more direct comparison with Clemence's results.

The observations were analysed, and discussed, during 1966. The full discussion is given in N.A.O. Technical Note Number 12, *Corrections for Irradiation to the Observed Altitude of the Sun* by W. A. Scott and D. H. Sadler; this Technical Note has not been formally published, but a copy may be obtained on application to H. M. Nautical Almanac Office. The summary reads:

'An analysis of 7280 observations, made specially for the purpose, gives a mean value of the difference of the irradiation corrections for the upper and lower limbs of the Sun of about $+0'.1$. This differs significantly from the currently adopted value of $+1'.2$, which was deduced from observations made at very low altitudes. A series of 668 observations made specially at low altitudes by officers at H.M.S. *Dryad* gives a mean value of about $+0'.8$, and strongly suggests that the difference increases sharply as the altitude decreases below 10°. It is concluded that there is little justification for retaining the present correction of $-1'.2$ in the altitude-correction for the upper limb of the Sun as given in *The Nautical Almanac*.'

After consultation with Dr. Clemence and the U.S. Naval Observatory, the correction was discontinued after the 1969 edition; although not so stated in the Summary, one consideration was that very few observations are made at low altitudes.

Perhaps the most interesting point brought out by the analysis was that the irradiation-difference d drifted during the 5 minutes, or so, of a series of observations by almost as much as the variations between series and between observers; these drifts are undoubtedly real, so much so that an observer could be recognized by the characteristic pattern (for example, slow rise followed by a more rapid fall) of his observations. As during this short time there was generally no variations in conditions, this must be due to the individual physiological conditioning of the observer. This clearly does not apply to the normal single observation made in practice; accordingly, the 228 first observed values of d from the series of N.A.O. observations were analysed separately; the resulting mean value of $+0'.14$ accords with that from all the N.A.O. observations.

Dependence on physiological conditions that vary not only from individual to individual but also from day to day and even during the course of the observations makes it clear that any correction applicable in the normal practice of navigation at sea cannot be reproduced by planned observations; any special requirements, which are essential to remove large accidental and systematic errors from other sources, will certainly affect the physiological condition of the observers. Many thousands of normal observations, fully recorded, would be required to isolate the average irradiation correction for all observers. There is still much to be learnt about irradiation and about the dip of the horizon; an observational programme, possibly using the artificial islands of the light towers and oil rigs, might well add to our knowledge. Even so, it is unlikely that it would be practicable to incorporate any but the simplest corrections in the altitude-correction tables. I think this answers Captain Cotter's final question.

As to his other question, it is my impression that the currently adopted formula for dip does not contain any term depending on irradiation and is consistent with a mean value of the horizontal refraction.

It might be added that the analysis, which was comprehensive, revealed no

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significant relationship with any specific factor. However, the standard error of the individual sightings increased rapidly with deteriorating conditions of sharpness of the horizon. The most experienced observers obtained, in good conditions, a quite remarkable consistency; but all observers recorded anomalous sights as the horizon became indistinct or difficult to observe, often *before* they thought it necessary to record the conditions as poor.

'Behaviour Patterns in Encounters between Ships'

G. R. Spooner

A FEW hours after reading the above article in the October *Journal* an incident occurred which highlighted the dangers indicated by Captain Kemp. At night, but in clear weather and deep water, and with no navigational hazards, a ship was reported at Green 30, 3 miles, with a C.P.A. of 2 cables to starboard. This was unnecessarily and dangerously close and the officer-of-the-watch (a relatively inexperienced watchkeeper) proposed standing on to 1 mile and then altering 10 degrees to port to open the range.

We were the burdened vessel and I considered this action wrong; too little and too late. An immediate turn to starboard was ordered to leave the other vessel clear to port and to make our intentions clear. Before the officer-of-the-watch could alter, the other vessel was seen to alter to *port*. We therefore held our course and he passed clear up the starboard side. This is one of the situations envisaged in the paper; had we made our turn to starboard in accordance with the Rules, a close-quarters situation would have developed at a very short range—with a greater ambiguity with regard to the subsequent actions in both ships.

The problem appears to be in deciding at what range ships should assume the full responsibilities within Rules 21 and 22. My officer's assessment was based on radar tracking confirmed by visual bearings. It is not known what sensors were available, or used, in the other vessel; and this will almost invariably be the case. You have no means of knowing how the other vessel has assessed the situation.

Although the Rules are reasonably clear on the action to take they are very vague about when this action should be taken; 'positive, early action' will be interpreted differently by every mariner. Small coasters seem to accept miss distances of 2 cables with equanimity and are sufficiently manœuvrable to take avoiding action at close range, but with larger vessels action must be more positive and taken far sooner, a fact which does not appear to be recognized in many small vessels. A captain of an aircraft carrier has stated that if a vessel approached within 2 miles forward of the beam without making her intentions clear there was very little that the carrier could do to avoid a collision. In the case of VLCCs I imagine that this range could be increased to 3 or even 4 miles.

Nowadays nearly every vessel carries radar (although a distressing number do not operate it in good visibility, relying solely on the judgment of the officer-of-the-watch) and it should therefore be possible to establish an advisory, if not mandatory, range within which ships *must* be bound by the regulations.