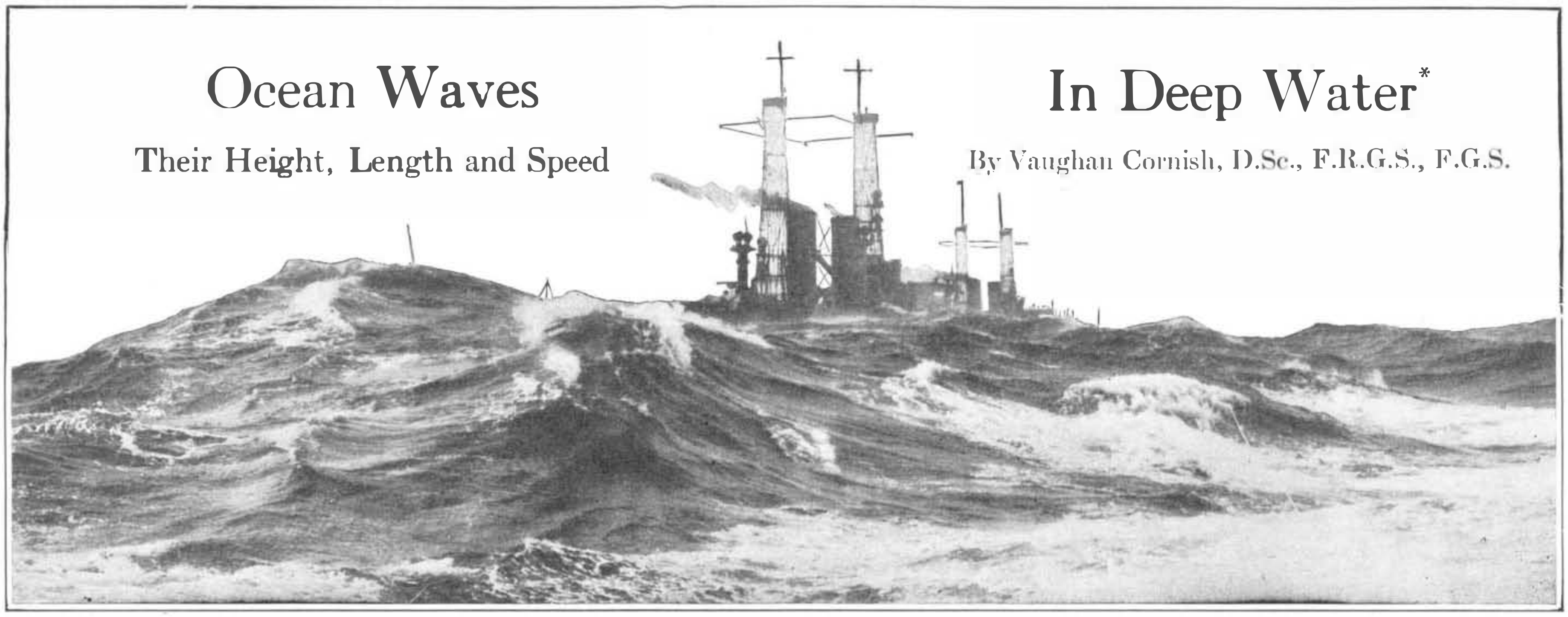

Ocean Waves In Deep Water*

Their Height, Length and Speed

By Vaughan Cornish, D.Sc., F.R.G.S., F.G.S.

In a former paper[1] I examined the observations of heights of waves in the deep sea as recorded by officers of the French navy, and showed that the average height of the waves increased proportionately to the increase in the velocity of the wind, so that velocity of wind in statute miles per hour = 2.05 × *average* height of the waves in feet; or, in other words, the average height of the waves in feet was very nearly one half the velocity of the wind in statute miles per hour.

In a later publication[2] I gave particulars of the height of the waves in a limited number of storms at sea, in which the waves seemed to have attained their full development, some of the cases being my own observations, others those of observers who had sufficiently recorded the attendant circumstances of position and weather. These heights are, of course, greater than those given by the constant in the above empiric formula, but they are not inconsistent with direct proportionality to the velocity of the wind, using a higher constant, such as 0.7 instead of 0.5.

When preparing the first cited paper—that of 1904—I had examined also the lengths of waves recorded by the French observers, but found that their relation to the velocity of the wind was so variable that I abandoned for the time being the attempt to obtain an empiric formula connecting the two quantities. It was apparent that although the waves soon attained, in the open sea, a height not far short of the highest possible, yet the measurements were often made while the growth of length was still far from complete. Conversely, if measurements were made soon after the wind began to decrease, the height of the waves had appreciably diminished, but their length had not.

I have since found that, by restricting the examination of figures to cases where the record of weather and position shows that the wind has had time and opportunity to complete its work, consistent results are obtained connecting the observed speed of the waves with that of the wind. In some of these cases the length of the waves has also been directly observed. The fact that waves driven by the wind have very nearly the same length as those of the same speed traveling by gravitation alone in calm weather is sufficiently established by observation to allow the length to be calculated from the observed speed in the remaining cases, and *vice versa*. The following records by other observers are among those selected as satisfying all requirements in my book on waves, written before I had hit upon the numerical relation which is the subject of the present lecture. Their selection from among many was, therefore, quite unbiased.

Lieutenant Paris, of the French navy, in a storm in the Southern Indian Ocean which lasted four days, observed during the first day a wave-length of 371 feet, corresponding to a speed of 30 statute miles per hour, but during the fourth day a length of 771 feet, corresponding to a speed of 43 statute miles per hour. The velocity of the wind was 46 statute miles per hour; so that during the first day it blew across the ridges of the waves at 46 — 30 = 16 statute miles per hour, but during the last day its excess speed was only 3 statute miles per hour—i. e., the highest waves were traveling with a speed nearly equal to that of the wind. Thirty waves were 29.5 feet high, six were 37.7 feet and some were higher than this.

In an exceptionally prolonged storm in the Southern Indian Ocean, Captain David of the steamship "Corinthic" recorded waves of an average length of 675 feet, with a calculated velocity, therefore, of 40 statute miles per hour, the wind being 44 statute miles per hour—i. e., with an excess velocity of only 4 statute miles per hour. The heights of the waves ranged from 38 feet to 45 feet.

The following observations by the Hon. Ralph Abercromby are among those which I have often cited as being some of the most fully described. On the voyage between New Zealand and Cape Horn, on June 10th, 1885, the velocity of the wind was 31 statute miles per hour, rising in some squalls to 37 statute miles per hour. He measured waves of velocity 32, 35, 39.5 and 28.5 statute miles per hour, the average velocity being, therefore, 33.75 statute miles per hour. The lengths of those traveling at 32, 35 and 28.5 statute miles per hour were measured, and found to be 507 feet, 470 feet and 358 feet—average 445 feet. Individual waves were measured with heights of 26 feet, 21 feet, 23.5 feet and 26 feet, or an average of 24 feet; but a sensitive aneroid registered a total rise and fall of 35 feet, which I explain by the supposition that there was a swell running with a height of 11 feet. Thus the velocity of the high waves was not less than the average velocity of the wind.

In a storm in the Bay of Biscay on December 21st, 1911, I had the opportunity of seeing large waves in final and regular development. They were produced by a wind which happened to have precisely the same direction as a regular and heavy swell which was already running. The waves rapidly increased in height, speed, and length, until we enjoyed the unusual spectacle of perfectly regular storm-waves with no "swell," no noticeable minor waves and no crossing of wave-crests. The ship—P. & O. steamship "Egypt"—was hove-to at about 3:30 A. M., and rode out this storm until about 1 P. M. I observed the waves from 8 A. M. until 1 P. M., both from the promenade deck with an eye-height of 27 feet, and from the captain's bridge with an eye-height of 54 feet. The sun was shining and the weather clear, and every circumstance combined to make observations unusually easy and satisfactory. The ship being held stationary, head on to the waves, the real and the apparent speed of the waves were the same, and the ship's length gave a base of measurement for the distance between two crests viewed simultaneously from the bridge without correction for difference of direction. The ship's length gave the base for calculating the speed from the time of traversing the distance from stem to stern as seen from the bridge, also without correction. This time, combined with the period, gave a second mode of observation of the length.

The period gave also a means of comparing the calculated length with the observed length of a wave. These measurements were made at noon. The agreement is sufficiently good to give me confidence in deducing the length of the waves at 10 A. M. and 8 P. M. from the period then observed. The velocities of the wind are obtained by taking the mean of two sets of estimations:

	Beaufort's number.		Velocity s.m.p.h.
Wind at 4 A. M....	9	10	48.5
Wind at 8 A. M....	9	9/10	46.5
Wind at noon......	8/7	8	35.5

The waves observed were:

Time.	Period observed.	Length calculated from period.	Length observed by simultaneous crests.	Length observed indirectly.	Speed observed in s.m.p.h.	Speed calculated from period in s.m.p.h.
	Seconds	Feet	Feet	Feet		
8 A. M........	13.5	933	.....	.....	.....	47.15
10 A. M.......	12.5	821	.....	.....	.....	43.66
12:15 P. M....	11.27	651	612	708	42.74	39.37

[The above calculations are performed with the precise factors used in the General Formula (see *post*). The figures quoted from my book on "Waves of the Sea" are calculated by a somewhat rougher approximation.]

At 10 A. M., with an eye-height of 27 feet, almost every wave passed considerably above my line of sight, and I estimated this excess of height at 4 feet, which would make them 31 feet in height. There was a remarkable approach to uniformity in height, the sea differing in this respect from that in which there is a swell running at the same time as the shorter storm-waves. Being occupied with measurements of length and speed, I had not time to make a detailed examination of the heights by seeking different elevations on the ship which would place me on a level with the lowest and the highest waves. Judging, however, from the general appearance, coupled with the experience of measurements on former occasions, I should say that there were few waves which differed by more than 5 feet from the average, which would make the range of height, except in isolated instances, only about one third of the mean, viz., from 26 feet to 36 feet.

The above observations show that the highest series of waves—which, indeed, was the only series visible—were traveling at a speed almost if not quite as great as that of the wind by which they were produced.

So much for the speed of the highest waves I have observed at sea during storms. I proceed to describe observations of the period—and, by theoretical calculation, the speed—of the waves which reach the seashore as breakers.

On December 29th, 1898, I observed at Branksome Chine, on the Dorset coast, between Bournemouth and Poole, 139 consecutive breakers with an average period of 19 seconds, and therefore a calculated velocity when in deep water of 66.5 statute miles per hour and a deep-water wave-length of 1,850 feet. There were very strong winds on the Atlantic from December 25th to 29th, 11-12 of Beaufort's scale (64-77 statute miles per hour) being recorded on ships. On land 77 statute miles per hour was recorded at Alnwick, Northumberland, at 10 P. M. on the 27th, and 71 statute miles per hour at 2 A. M. on the 28th. Waves 45 feet to 52 feet high were reported in N. 47 deg. W. 19 deg. on December 29th from steamship "St. Simon," but I have no details as to how the heights were estimated.

On February 1st, 1899, I observed 12 consecutive breakers at Branksome Chine with an average period of 22.5 seconds, which is the longest period I have ever observed. Their calculated speed in deep water is 78.75 statute miles per hour and their wave-length 2,594 feet. Owing to the exceptional violence of the winds during this season the Meteorological Office collected all available data of weather in the North Atlantic, and published an atlas showing the size and position of the depressions and the direction and strength of the

* Cantor lecture, published in the *Journal* of the Royal Society of Arts.

[1] *Geographical Journal*, May, 1904, "On the Dimensions of Deep-sea Waves," etc.

[2] "Waves of the Sea and Other Water Waves," by Vaughan Cornish. (Fisher Unwin, 1911.)

COMPARISON OF OBSERVED DIMENSIONS OF WAVES WITH THOSE CALCULATED BY THE GENERAL FORMULA (the dimensions are given in feet).

Observer.	Description of wind.	Beaufort number (1-12).	Corresponding velocity of wind in s.m.p.h.	Observed velocity of wave in s.m.p.h.	Observed period of waves.	Period by the formula.	Observed height of prevalent waves.	Highest waves observed.	Height of the final waves by the formula.	Observed length of waves.	Length by the formula.	Observed ratio, length divided by height of the prevalent waves.	Ratio, length divided by height of final waves by the formula.	Locality.	Date of observation.	Remarks.
Cornish			21		6.8	6.0								Caribbean	Apr. 12, 1912	Wind dead aft; velocity of wind from smoke of funnel; steady wind; no swell.
Cornish	Strong breeze	6	25				15	Greater than 20	17.5	200	262	13.3	15.0	Caribbean	Jan., 1907	Between Colon and Jamaica. Trade wind exactly ahead.
Abercromby	Moderate gale	7 with 8 in squalls	32	33.75			21 to 26 average 24	26	22.4	445	430	18.5	19.2	S. Pacific	June 10, 1885	Aneroid showed total rise and fall, 35 feet.
Scoresby	Fresh gale	8	37				26		25.9	560	575	21.5	22.2	N. Atlantic	Mar. 6, 1848	800 geographical miles from windward shore.
Cornish	Strong gale	9	44				29	43 in peaks	30.8					Do.	Dec. 7, 1900	1,000 geographical miles from windward shore.
Scoresby	Do.	9	44				30	40	30.8					Do.	Mar. 5, 1848	600 geographical miles from windward shore.
David	Do.	9	44				40 to 45	One of 50	30.8	675	813	15.9	26.4	S. Indian	Aug., 1907	
Paris			46				30 waves of 29.5 feet	6 waves of 37.7 feet, and some higher	32.2	771	889	26.1	27.6	Do.	Oct., 1867	
Cornish			46.5		13.5	13.3	Greater than 31		32.5					Bay of Biscay	Dec. 21, 1911	Ship hove to; observations unusually easy.
Cornish	Storm to hurricane recorded at sea	11 to 12	64 to 77		19 to 22.5 swell observed on shore	18.3 to 22		45 to 52 reported at sea	44.8 to 53.9					Dorset Coast	Dec., 1898 and Feb., 1899	Data for weather and waves in the Atlantic from a report of Meteorological Council; observations on shore by Cornish.

winds. It shows nothing on January 31st or February 1st to account for the swell observed at Branksome Chine on February 1st; but on January 30th there was a solitary deep depression with wind a little S. of W. of force 11-12—i. e., velocity 64-77 statute miles per hour. From the actual situation of the depression this direction is true for the entrance to the English Channel. In order that the waves should reach Branksome Chine at the time of my observation they would have to advance at a speed of 40.8 statute miles per hour.

The waves which I observed traveling individually at 78.5 statute miles per hour, would advance *as a group* at half this speed, viz., 39.75 statute miles per hour. As no wind force 11-12 was recorded at sea on January 31st and February 1st, the height of the individual waves would not be maintained by the wind, and the front member of the group would continually be dying out, to be replaced by a new member in the rear, so that it is the group velocity and not the individual velocity which has to be calculated in tracking these waves to their source.

There is considerable probability, therefore, that the waves with an individual velocity of 78.5 statute miles per hour, which I observed at Branksome Chine, were produced by wind of velocity 64-77 statute miles per hour at 2,000 miles; that is to say, 4,000 wave-lengths' distance.

The question of the time during which these high velocities of wind were maintained must also be considered. During this stormy season an average velocity of 53 statute miles per hour (Beaufort's 10) was maintained, as observed on land, for 6 hours on January 12th, 1899, and 70-76 statute miles per hour for one hour.[3] During the same month a velocity of 80 to 90 statute miles per hour was attained by gusts of wind.[4] The highest recorded velocity in any gust of wind of which I have knowledge is 103 statute miles per hour.

Thus the greatest velocity of waves calculated from the longest periods of breakers which I have observed is practically equal to the speed of the wind as indicated by the highest logged numbers at sea, and the highest average velocity of wind maintained for one hour on land during the same season. I should add that the group of 12 breakers of 22.5 seconds period were of not inconsiderable size, considering the somewhat sheltered situation in which they were observed, and the group of 19 seconds period (66.5 statute miles per hour) were unusually large. Thus the observations indicate, first, that waves traveling as fast as the average velocity of the strongest winds form large breakers upon the shore; and, secondly, that if there be swifter waves produced directly or indirectly by the action of wind upon the sea, they do not attain sufficient height to form noticeable breakers.

Combining the results of the observations at sea with those from the shore, I consider that I am now in a position to propose a settlement of the long-debated question of a formula which shall express the connection between the speed of the wind and the dimensions of the highest waves which it produces in deep sea far from land. As already stated, the records of average height in feet observed at sea are approximately equal to half the velocity of the wind in statute miles per hour. For those occasions on which the wind has had as full opportunity as it ever enjoys of doing its work, direct proportionality still holds good, but the constant is higher. I find that seven tenths best satisfies the available observations between a strong breeze and a whole gale. The same simple proportion would not hold if we began with the heights corresponding to the gentlest breezes, which would probably rise in a steepening curve; but the only part of the line which is of nautical importance is that part which comprises waves of considerable size, and this part is a straight line.

My chief difficulty in obtaining a general formula has hitherto been the determination of the relation between wave-length and velocity of the wind. Having now, however, found that the highest waves finally formed are those traveling at a velocity which is equal, within the errors of observation, to that of the wind, their length can be directly calculated from the observed velocity of wind. I thus obtain the table given below which shows the height and length, and, therefore, also the steepness, of the highest waves finally produced in deep sea far from sheltering land by winds of the different velocities corresponding to the numbers from 6 to 12—strong breeze to hurricane—on Beaufort's table of wind force.

It will be noticed that, since I find the velocity of the waves to be equal to that of the wind, their length, according to the theory of waves, is proportional to the square of the velocity of the wind. Now I find the height to be proportional to the velocity of the wind. The height divided by the length—that is to say, the steepness—of the waves is, therefore, inversely proportional to the velocity of the wind. The table gives the steepness of the highest waves formed by wind of any velocity, but the waves are steeper before they acquire their final speed and greatest height.

In the table two constants depend upon observations, viz., the equality of velocity of wave and velocity of wind, and the factor 0.7 for converting velocity of wind in statute miles per hour to height of wave in feet. The other factors employed are given by the theory of trochoidal waves traveling in deep water.

GENERAL FORMULA FOR CALCULATING THE LENGTH AND HEIGHT OF THE WAVES FINALLY PRODUCED IN THE OPEN SEA BY THE ACTION OF WINDS OF ANY VELOCITY FROM 25 TO 77 STATUTE MILES PER HOUR.

This formula is based upon—(1) The observation that in prolonged storms, or when the wind blows directly upon a swell of less than its own speed, the waves travel with the same speed as the wind, within the limits of the errors of observation. (2) The observation that the breakers of longest period have a calculated deep-water velocity equal to the maximum average velocity of wind recorded for the same spell of weather. (3) The observation of heights of fully-developed waves at sea. (4) The relation between speed, period and length of waves given by the theory of trochoidal deep-water waves; employing the formula — speed of wave in feet per second = 5.123 × period = $\sqrt{5.123 \times \text{length}}$ (*vide* Chapter V. of Sir Wm. H. White's "Naval Architecture"), and converting from feet per second into statute miles per hour by use of the factor 0.6818.

Description of Wind.	Beaufort's number for wind-force.	Velocity of wind (V) in statute miles per hour = Velocity of wave.	Period in seconds = $V \div 3.493$.	Length in feet = $V^2 \div 2.382$.	Height in feet = $V \times 0.7$.	Length ÷ Height = $V \times 0.600$.
Strong breeze	6	25	7.2	262	17.5	15.0
Moderate gale	7	31	8.9	404	21.7	18.6
Fresh gale	8	37	10.6	575	25.9	22.2
Strong gale	9	44	12.6	813	30.8	26.4
Whole gale	10	53	15.2	1,180	37.1	31.8
Storm	11	64	18.3	1,720	44.8	38.4
Hurricane	12	77	22.0	2,489	....	....

Note on the Height of Waves.—The figures are for the average waves. When their speed is equal to that of the wind, there is not the great variation in height which occurs when the wind has a velocity less than that of the swell left by a preceding storm and occasional high waves are formed by superposition.

Note on the Length of Waves.—When the length is judged by the apparent distance which separates two wave-crests viewed simultaneously, the result is generally much less than the true length. Unless special precautions are taken, the eye is completely deceived. Reliable results are obtained by determining the time occupied by the waves in running the length of the ship combined with the interval of time between the arrival of the waves. This mode of measurement is, of course, independent of the theory of the relation between period and length.

Note on "Force 12."—A short group of breakers of the corresponding period have been observed by the author; but there is no reliable record of a sea in which the height of the waves averaged 53.9 feet, presumably on account of the extreme force of wind not being long maintained. Breakers corresponding in period to force 11 have been recorded in a long series.

I anticipate that seamen will object that the wave-

[3] F. J. Brodie, *Quarterly Journal of the Royal Meteorological Society*, 1902.

[4] *Symond's Meteorological Magazine*, May, 1900.

lengths given in the table exceed their experience of the apparent length of waves. I have pointed out elsewhere[6] that although there is agreement between the records of systematic observation of heights of waves and the experience of navigating officers, there is a discrepancy in the matter of wave-lengths. Wave-length in the case of systematic observations has generally been determined indirectly by noting the time occupied by a wave-crest in running the length of the ship and the interval of time between the arrival of successive waves. The result is to give wave-lengths much greater than those generally assigned by officers on the bridge who notice the apparent distance between contiguous wave-crests viewed simultaneously. Only in the case of very long and regular waves, such as those seen in westerly storms in the Southern Ocean, is there an approach to concordance. For ordinary rough weather in the North Atlantic the discrepancy is about 100 per cent, the general estimate of seamen being about one half that obtained by systematic observation of succeeding waves. Observing from the promenade deck of passenger steamers, I found my estimate of the apparent length of waves viewed simultaneously agreed, on the whole, with that of the navigating officers, and was much less than that calculated by theory from my observation of the periods. It was only on my voyage in December, 1911 (Marseilles to Plymouth by P. & O. steamship "Egypt"), that I was able to satisfy myself as to where the truth lay. On December 19th, off the coast of Portugal, there was a heavy swell occasionally rising to more than 20 feet, and with a period of about 11 seconds. I came to the conclusion that when judging the distance between crests of succeeding waves along the ship's side my eye had in the past been deceived owing to the steep slope at the shoulder and the almost flat top of the waves. I decided that I had taken points a little beyond the *shoulders* of the receding and advancing waves as their summits, and thus systematically underestimated the wave-length by a large amount. Two days afterward I had an opportunity of testing the matter, and convinced myself that the appearance which had so long deceived me commonly deceives even the practised eye of the seaman. When on the passenger deck of the steamship "Egypt" at 9 A. M. of December 21st, the day of the storm already referred to, I was unable to satisfy myself whether the waves were or were not as long as the ship—512 feet. I had not the opportunity of obtaining at the moment the opinion of a navigating officer, but one of the engineer officers was good enough to address himself to the subject. He judged the length of the waves to be about 200 feet. As we were hove-to head to wind, the conditions were favorable to observation. Going onto the navigating bridge, I had from this position of vantage no difficulty in deciding that the large and regular waves were longer than the ship, for the stern was on one crest when the next crest had not yet arrived at the dipping bow. I estimated the wave-length at 100 feet longer than the ship, and this estimate was approximately confirmed by the indirect measurement of length, and both were in fair agreement with the length theoretically calculated from the period. A navigating officer who co-operated with me in observing the same waves as they took the ship within their length, estimated their length at 542 feet as against my 612 feet; but another navigating officer on the bridge, who had been noticing the sea but not joining me in my systematic observations, judged the length of the waves to be 180 feet. The observations given in the table prove beyond reasonable doubt that the waves were quite 600 feet long. At the time when the engineer officer from the passengers' deck estimated the waves at 200 feet the observation of period gives their theoretical length at 800 feet, and my observations on the bridge proved that the lengths calculated from period were the actual lengths.

I do not think, therefore, that there is any longer room for doubt that, unless special precautions be taken or the circumstances be specially advantageous, the eye is completely deceived in judging the length of waves from the apparent distance between contiguous crests viewed from on board ship. Error is least when the eye is high above the waves.

[6] Waves of the Sea and Other Water Waves," 1911.

Electricity for Country Houses*

Generator and Accumulator

When electric light first became a domestic possibility, it was naturally somewhat of a luxury, on account of the high cost of all the various apparatus necessary for its production. Hence the private plant in the country houses of the rich was an early institution after the invention of the incandescent electric lamp and the accumulator. The plant of those days was, however, a very different thing from that which is installed now, and probably none of the earlier private plants are any longer in existence. There is no doubt that a good many of these were steam-driven sets—at any rate for very large mansions—and that the Willans engine found its place in many a large castle. Other residences, situated near hill or mountain streams, were provided with hydro-electric plants—that is, small water turbines as prime movers; and, of course, many such are still at work, and others would be installed were it not that in all probability the money to be sunk for the structural and engineering arrangements would considerably exceed that required for a modern internal combustion engine.

As electric light became more popular for country houses, the demand for gas and oil engines of smaller sizes increased, and a very large business was done with these. Where a house was situated near the gas mains of the local town, gas-engines were nearly always employed, while, in practically every other case oil-engines were used. The oil-engine of twenty years ago was a very different type of machine from that now offered for country house plants. It is not our object to go deeply into technical details in this article, so it will suffice to say that the engines of that day were cumbersome, required a lot of attention, and burned kerosene oil in a rather uneconomical manner. Gas-engines, too, were by no means so economical as now, nor was either engine produced in the small sizes in which they are to be had to-day, because the various current-consuming devices were all more inefficient. The art of designing dynamos was in its infancy, and small machines of the two-pole type were employed, which ran very well, but inefficiently. Accumulator batteries had to be large to cope with the relatively large amount of current required, and were also inefficient and suffered considerable annual depreciation. Finally, the incandescent electric lamp consumed at least 4 watts per candle-power, and often more, and was actually, as it is now, the means of dictating the size of generating plant and accumulator battery.

With the advent of the metal filament lamp, however, everything underwent a change, although this took place gradually. Simultaneously with these new lamps, the gasoline engine appeared on the scene to meet the demand for a smaller high-speed prime mover, and this caused makers of gas and kerosene engines to design smaller and more efficient patterns in order to meet this one form of competition. Generally speaking, the metal filament lamp may be said to consume about one third the amount of current required by the old carbon filament lamp for equal light, and, although its initial price was $1.25,[1] and its present price is 50 cents compared with the 25 cents or less of the carbon filament lamp, it holds its own practically everywhere on account of its reduced current consumption. It is, therefore, clear that with generating plants of only about one third the original capacity the number of country house installations has largely increased, owing to the reduced cost of initial outlay, running, and maintenance, while the almost miniature engines which have been put on the market of late have brought electricity within the means of the owners of small villas and even cottages. In addition, the cost of wiring has been reduced by new methods which will not be discussed on this occasion so that, with the exception of the initial cost of the lamps, everything is in favor of the house-owner compared with the old days, and even the extra cost of lamps is more than compensated for by the saving in current, and therefore in fuel.

In regard to the choice of a suitable engine for country house lighting, a great deal depends on individual requirements and local conditions. The two chief factors are the size of plant required and the nature of the environment. For instance, the amount of lighting may be small, but the user may require current for electrical cooking, heating and power, so that the plant might actually have to be a fairly large one even for a small house. Then there may be water power available, or wood or coal may be very cheap, while gas or oil may be expensive, or there may be no gas at all. Speaking generally, the following suggestions may be offered for determining the choice of a plant:

(1) For houses requiring a small amount of current:

(*a*) If situated in the country, a kerosene or gasoline set.

(*b*) If near a town with cheap gas, a gas-engine set.

(2) For houses requiring a large amount of current:

(*a*) If situated in the country where there is water power, a hydro-electric set.

(*b*) Ditto, where coal or wood is cheap, a steam set (particularly if the steam can also be used for heating and laundry purposes).

(*c*) If situated anywhere else, a suction-gas set.

These suggestions are offered entirely on the basis of economy in working, but there may be reasons for modifying them. For instance, the initial cost of obtaining water power may not warrant the installing of such a plant, however cheap to operate, or there may be advantages in using suction gas or kerosene even where wood or coal is cheap. However, everything must be taken thoroughly into consideration, if running economy is an object; but where it is not, it is much better to adopt the kind of plant that best meets all other requirements and that gives as little trouble as possible. As economy is the chief consideration, we shall assume for the present that a water power or steam plant is too expensive to install and to maintain, and confine ourselves to the consideration of gasoline, kerosene, gas and suction-gas plants. The advantages of these plants over hydro-electric and steam plants are that they all occupy very little space, require much less initial expense, and can generally be managed without additional labor. There is still a very prevalent idea that an electric light plant costs several thousands of dollars, and an extra man to work it, and no doubt this serves to frighten many people and to prevent them even considering the question of an electric light plant. These things may have been true some years ago, for the reasons already given, but the modern plants have been so well standardized and designed on such compact and almost fool-proof lines that small gasoline sets can be obtained complete with battery, switchboard, and wiring for less than $500 for the lighting of bungalows, shooting boxes, etc.

All these country house plants comprise essentially three main parts—the generating plant, the battery, and the switchboard—and they require very little in the way of housing. Any suitable outhouse will do for the smallest sets, the space for the battery being partitioned off in order to prevent the sulphuric acid fumes from damaging the generating plant. Where there is no outhouse available, or where larger sets are installed, space may be found in a basement, or it is necessary to build a special housing. The object of the battery of accumulators is that the engine and dynamo may be run during the day time, where there is a gardener or similar person about who can give them the necessary small attention required. The dynamo charges the battery during this period, and the battery is used at night to supply the necessary current for the lamps. Arrangements are generally made for supplying the lights direct from the dynamo, if required, or for running the dynamo and battery direct on to the lights at night if there is an extra load.

Generally, however, the battery is quite capable of meeting the average demand, and often it is only necessary to charge the battery every other day. Each cell of the battery requires 2.5 volts to charge it, and discharges at about 2 volts down to 1.8 volts. If, therefore, the voltage of the lamps is 50 volts, 25 cells are required, and the dynamo must be capable of regulation from 50 to about 63 volts. As the voltage of the battery falls to 1.8 volts per cell, a few extra cells are provided, which are thrown in one by one during the discharge, and for this reason the voltage of the dynamo must be higher by the amount of these extra regulating cells. For instance, to supply 50 volts at 1.8 volts per cell, twenty-eight cells will be required, and by the time all are working it is time to charge the battery again. There is some loss of energy due to the charging of the cells, but this is compensated for by the additional convenience of the battery and the absence of necessity of running the engine and dynamo at night. The engine and dynamo are usually direct coupled on a common bedplate, which occupies very little room, and the other accessories of the plant comprise an oil tank and a water tank and pipe work for circulating cooling water round the cylinder or cylinders; but these parts are quite simple and do not present any difficulties. The switchboard is generally placed in the engine-room, and consists of a slab of marble or slate, mounted with the necessary measuring instruments, regulating and controlling apparatus for charging and discharging. The battery comprises a series of glass boxes on wooden stands, which are generally arranged in two tiers.

Gasoline-electric sets are, as previously stated, recommended for small houses where only a few lights are re-

*Reproduced from *The Builder*.

[1] The prices quoted throughout this article refer to English conditions.