taper. A feeble line in the yellow was coincident, under the conditions employed, with the sodium line at D.

The hydrogen line at G was distinctly seen, as well as a band or group of lines between G and F.

Nearly all the lines appear to be approximately, if not actually, coincident with the lines seen in the various types of Cygnus stars, the chief difference being the apparent existence of carbon, hydrocarbon, and calcium in the nova.

The colour was estimated by Mr. Fowler as reddish-yellow, and by Mr. Baxandall as rather purplish. My own impression was that the star was reddish, with a purple tinge. This was in the 10-inch achromatic. In the 3-foot reflector it was certainly less red than many stars of Group II. No nebulosity was observed either in the 3-foot or the 10-inch refractor, nor does any appear in a photograph of the region taken by a $3\frac{1}{2}$-inch Dallmeyer lens with three hours' exposure. It should be stated that the camera was carried by the photographic telescope, the clock of which had had its normal rate purposely changed to give breadth to the spectrum.

The photographs were taken and reduced by Messrs. Fowler and Baxandall. The eye observations and comparisons were made by Mr. Fowler alone.

II. "Note on the Energy Absorbed by Friction in the Bores of Rifled Guns." By Captain NOBLE, C.B., F.R.S., &c. (late Royal Artillery). Received December 31, 1891.

The object of the experiments which I proceed to describe was to ascertain approximately, and under varied conditions, the loss of energy due to the friction of the driving ring of the projectile in the bores of rifled guns.

The rotation of modern breech-loading projectiles is generally given by means of a copper ring or band on the projectile, on a plan originally proposed by Mr. Vavasseur, the diameter of this ring being not only somewhat larger than that of the bore, but even larger than the diameter of the circle representing the bottom of the grooves, and the projections which give the rotation are formed by the pressure of the powder gases forcing the driving ring into the grooves of the gun. At the commencement of motion the driving ring is consequently exactly moulded to the section of the bore at the seat of the shot, and under the conditions due to the pressure to which the gun is at the moment subjected.

It will readily be conceived that a band or ring, moulded as described, may give rise to considerable friction in its passage through the bore, and the amount of this friction may be modified to a considerable extent by various circumstances.

For example, the nature of the powder employed may, depending on the deposit or fouling left in the bore, affect appreciably the friction. Again, the friction may be considerably modified by the form and diameter of the ring itself, while a variable amount of energy must be absorbed by the methods employed to give rotation, and by the amount of that rotation.

In the preliminary experiments three descriptions of powder were employed—(1) the powder known as P, or the pebble powder of the English Service; (2) an amide powder in which the nitrate of potassa of ordinary powder is largely replaced by nitrate of ammonia, and which powder, in addition to other valuable properties, gives rise to a smoke much less dense and much more rapidly dispersed than is the case with pebble and other similar powders; and (3) a true smokeless powder. The form of smokeless powder employed in this country is best known under the name of *cordite*, a propelling agent which promises to be of great value, and for which we are indebted to the labours and experiments of Sir F. Abel and Professor Dewar. A somewhat similar explosive is employed abroad under the name of "ballistite," and with this explosive also I have been able to make an interesting series of experiments. These experiments do not, however, come within the scope of the present note.

The preliminary experiments having shown that a very considerable amount of friction was, in the case of pebble powder, due to the fouling of the gun, while no such result was observed either in the case of the amide powder or the cordite, it was determined to carry out the subsequent experiments with the amide powder, firing, however, for purposes of corroboration an occasional round with the cordite, of which a small quantity only was available.

It may be of interest to note the loss of velocity and energy due to the fouling with pebble powder. The charge of powder in a 12-cm. gun being 12 lbs., and the weight of the shot 45 lbs., the velocity of the shot, the gun being carefully cleaned and oiled, was, in three trials, respectively, 1877 ft.-secs., 1877 ft.-secs., and 1878 ft.-secs. The two rounds fired immediately afterwards, the bore then being foul, were respectively 1850 and 1868 ft.-secs., 1848 and 1847 ft.-secs., 1852 and 1847 ft.-secs., or, taking the means of the whole series, the mean velocity with the gun clean was 1877·3 ft.-secs., with the bore foul 1852 ft.-secs., or, to put the result in another form, the mean energy realised from the pebble powder, the bore being carefully cleaned, and allowance being made for the energy of rotation, was 1102 ft.-tons, while the mean energy similarly realised with the bore foul was only 1072 ft.-tons, showing a loss of 30 ft.-tons or of 2·73 per cent. of energy attributable to the extra friction due to the powder deposit in the bore.

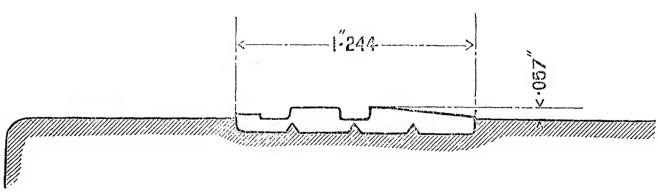
For the purposes of the subsequent experiments, three 12-cm.

quick-firing guns were specially prepared and rifled in the following manner:—The first had grooves of the usual section of the Service, but these grooves were all cut parallel to the axis of the bore, that is to say, the pitch of the rifling was infinite, or, in other words, there was no twist, and no rotation round the central axis would be communicated to the projectile; the second gun was rifled with a uniform pitch of 1 turn in 162 inches (about 1 turn in 35 calibres); while the third gun was rifled with a uniformly-increasing pitch of from 1 turn in 472″·5 at the breech to 1 turn in 162″ at the muzzle, so that in the last two guns, assuming the same muzzle velocity, the projectiles would leave the gun with the same angular velocity.

The projectiles used in these experiments were flat-headed cylinders (all being made of the exact weight of 45 lbs.), and differed from one another solely in the driving bands of the projectiles, which differed from one another both in diameter and length, the differences being shown in the sketches attached to the tabular results.

The first experiments were made with the rings marked "A," three rounds being fired from each of the three guns described, and the following table shows the velocities and energies obtained from each nature of gun.

Table I.—Results of Experiments with Driving Rings Section "A."



Nature of rifling.	Muzzle velocities.	Muzzle energies.	Mean muzzle velocity.	Mean muzzle energy.
	ft.-secs.	ft.-tons.	ft.-secs.	ft.-tons.
No twist	2130 2124 2136	1416 1408 1424	2130	1416
Uniform rifling	2109 2104 2118	1394 1386 1405	2110	1395
Parabolic rifling	2079 2088 2076	1354 1365 1350	2081	1356

Now, if the results given in this table be examined, it will be observed that the whole of the velocities obtained from the gun without twist are higher than those obtained from the gun rifled with a uniform twist, while the whole of the velocities obtained from the last-mentioned gun are higher than those obtained from the gun with the parabolic or uniformly increasing twist.

Using the mean results, there is a loss of velocity of 20 ft.-secs. in passing from the gun with no twist to that with a uniform twist, and a further loss of 29 ft.-secs., or 49 ft.-secs. in all, in passing to the gun with the parabolic rifling. Translating these losses of velocity into losses of energy, it appears that there is a loss of 21 ft.-tons, or about 1·5 per cent. of the total energy due to the uniform rifling, and a further loss of 39 ft.-tons, or 2·75 per cent., making 60 ft.-tons, or about $4\frac{1}{4}$ per cent., in all when the parabolic rifling is employed.

In a paper published in vol. 45 of the 'Philosophical Magazine' (1873) I investigated the ratio existing between the forces tending to produce translation and rotation in the bores of rifled guns, and I showed that, if R be the pressure tending to produce rotation, and G be the gaseous pressure acting on the base of the projectile, the resultant of which pressure acts along the axis of the bore, that is, along the axis of Z, then in the case of the parabolic rifling

$$R = \frac{2\rho^2(Gz + Mv^2)}{\dfrac{(h^2k^2 + 4\rho^2z^2)\sin\delta}{\sqrt{\{4z^2(\sin\delta)^2 + k^2\}}} + \dfrac{2\mu_1 kz(\rho^2 - h^2)}{\sqrt{(4z^2 + k^2)}}} \quad \ldots\ldots\ldots \quad (1),$$

where r is the radius of the bore, ρ the radius of gyration of the projectile, k the principal parameter of the parabola (the plane of xy being supposed to be at the vertex of the parabola and at right angles to the axis of the bore), δ the angle which the normal to the driving surface of the groove makes with the radius at the point under consideration, v the velocity at that point, μ_1 the coefficient of friction.

While in the case of a uniform twist

$$R = \frac{2\pi\rho^2 G}{\dfrac{\mu_1(2\pi\rho^2k - rh)}{\sqrt{(1+k^2)}} + \dfrac{(2\pi\rho^2 + rhk)\sin\delta}{\sqrt{\{k^2 + (\sin\delta)^2\}}}} \quad \ldots\ldots\ldots \quad (2),$$

where h is the pitch of the rifling, k the tangent of the angle which the groove makes with the plane of xy, the other constants, &c., bearing the meaning I have already assigned to them.

Now to obtain the numerical values of R from the above equations, a knowledge of the values of G, that is, of the total pressures acting on the base of the projectile, and in the case of the parabolic rifling of the velocity at all points of the bore, is necessary, and, the explosives used being novel, for this investigation, as well as for other purposes, I have recently determined by direct experiments in the bore of a 12-cm. quick-firing gun the mean velocities and mean gaseous pressures at all points of the bore, both for the amide powder, mainly used in this investigation, and for cordite.

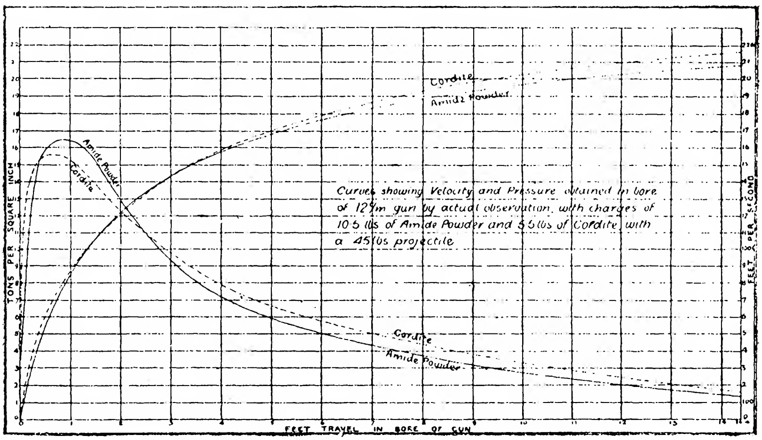


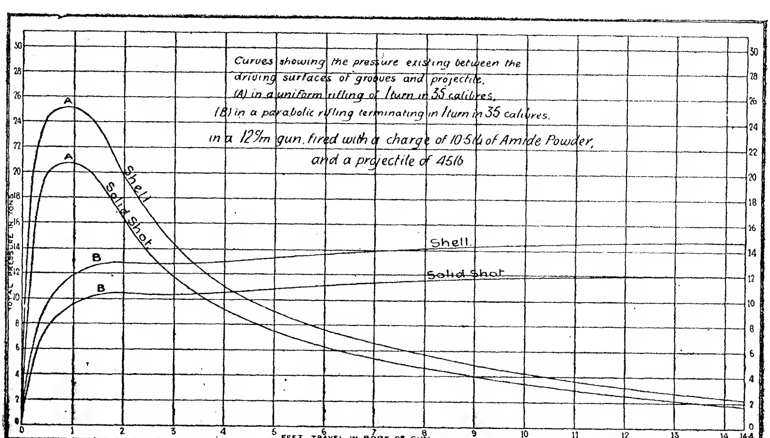
Table II.—Uniform Rifling, Amide Powder.

Travel of shot in bore in feet.	Total pressure, &c., on base of shot in tons.	Total pressure R between driving surface of grooves and ring of projectiles in tons.
0·5	254·7	19·9
1·0	264·0	20·7
1·5	245·0	19·2
2·0	207·9	16·3
2·5	175·7	13·7
3·0	150·7	11·8
4·0	115·2	9·1
5·0	94·9	7·4
6·0	80·6	6·3
7·0	69·5	5·4
8·0	60·0	4·7
9·0	52·1	4·1
10·0	44·8	3·5
11·0	38·4	3·0
12·0	32·9	2·6
13·0	28 4	2·2
14·0	24·3	1·9
14·4	22·6	1·8

The curve shown on p. 413 exhibits for the charges used and explosives I have named the results of these experiments, and, employing these values, the following tables give for uniform and parabolic rifling the value of R, that is, the pressure tending to give rotation calculated from formulæ (1) and (2). They also give the pressure acting on the base of the shot, and the velocity in the bore.

Table III.—Parabolic Rifling, Amide Powder.

Travel of shot in bore in feet.	Total pressure on base of shot in tons.	Velocity, ft.-secs.	Total pressure R between driving surface of groove and ring of projectile in tons.
0·5	254·7	548	7·9
1·0	264·0	849	9·7
1·5	245·0	1064	10·3
2·0	207·9	1224	10·5
2·5	175·7	1343	10·5
3·0	150·7	1437	10·4
4·0	115·2	1577	10·5
5·0	94·9	1680	10·8
6·0	80·6	1761	11·1
7·0	69·5	1828	11·4
8·0	60·0	1884	11·6
9·0	52·1	1931	11·8
10·0	44·8	1970	11·9
11·0	38·4	2004	12·0
12·0	32·9	2032	12·0
13·0	28·4	2056	12·1
14·0	24·3	2076	12·1
14·4	22·6	2084	12·1

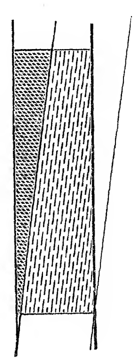


The values of R as given in the last columns of the above tables are graphically shown on p. 414, and from a comparison of the two curves it will be readily seen that, although the maximum pressure between the driving surfaces is not so high with the parabolic as with the uniform rifling, yet, as has been pointed out by Professor Osborne Reynolds, the mean driving pressure is with the parabolic rifling considerably higher, and as the energy absorbed by the friction between the driving surfaces is approximately proportional to the mean driving pressures, the loss of energy with that form of rifling is appreciably greater than with the uniform rifling.

In the experiments I am now discussing the mean driving pressure throughout the bore was, with the uniform rifling, 7·35 tons; the mean loss of energy due to the uniform rifling was 21 ft.-tons; hence the coefficient of the friction between the driving surfaces derived from these particular experiments is $\mu = 0·199$.

Again, with the parabolic rifling, the mean driving pressure throughout the bore is 11·06 tons, and if we had only a similar friction to consider, the loss of energy with this rifling should be proportioned to the pressure. The loss, however, is much higher, amounting, in fact, to 60 ft.-tons. Part of this extra loss must be ascribed to the continual alteration of form that the copper driving ring is subjected to in its passage up the bore,* but it seems to be doubtful if the whole of this loss can be ascribed to this cause. Part may possibly be ascribed to the ribs being continually forced, so to speak, to ride on to the sloping driving surface; but the number of rounds in each case being few, a part may possibly be ascribed to

* The action I refer to will readily be understood from the annexed diagram. If the thick lines represent the plan of one of the grooves at the initial angle of the rifling, the projections on the driving ring will be moulded into that form, and if the light lines represent the groove at its terminal angle it will be seen that the final form of the projections on the ring will be as shown by the shading, while the cross-hatched portion represents the metal removed by the action of the driving surface.



variations in the energy developed in the gun. Variations in energy, under precisely similar conditions, might easily amount to 1 or 2 per cent., or occasionally more, and, as will be subsequently seen, the differences between the uniform and parabolic rifling, although always in the same direction, are not the same in all the series, and the mean of the whole will probably give the most reliable result.

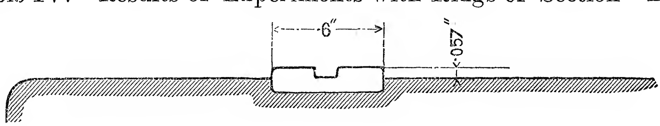
Summing up the results at which we have so far arrived in the experiments I have discussed, it appears that the total loss of energy arising from the fouling of pebble powder and from the friction due to the parabolic rifling together amounted to close upon 7 per cent. of the whole energy developed.

The third and subsequent series of experiments were made some weeks later, and from climatic or other causes there was a slight but decided decrement in the energy obtained with the amide powder. This decrement did not in any way affect the experiments except that the absolute values of the energies at the different dates are not strictly comparable.

The object of the third series was to ascertain if a narrow driving band would rotate the projectile equally well, as with an increasing twist it is important, if rotation be secured, that the breadth of the driving band be as small as is convenient, and further, as in the last series, to ascertain the loss of energy due to the uniform and parabolic rifling.

The results of this third series were as shown in the following table:—

Table IV.—Results of Experiments with Rings of Section "B."



Nature of rifling.	Muzzle velocity.	Muzzle energies.	Mean muzzle velocities.	Mean muzzle energies.
	ft.-secs.	ft.-tons.	ft.-secs.	ft.-tons.
No twist	2112 2104 2124	1392 1381 1408	2113	1394
Uniform twist	2109 2094 2095	1393 1373 1375	2099	1380
Parabolic twist.......	2067 2066 2066	1338 1337 1337	2066	1337

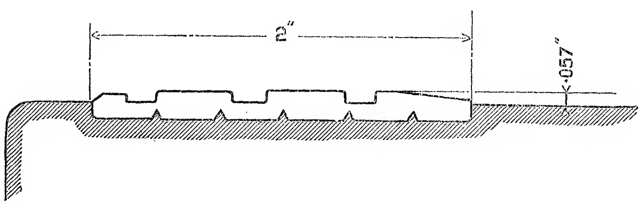
The results of this series confirm generally those of the previous series. The loss of energy due to the friction of the uniform rifling amounts to 14 ft.-tons, or, a little more than 1 per cent., while that due to friction and other causes with the parabolic rifling amounts to 57 ft.-tons or about 4·1 per cent., and nearly the same as before. The difference between the uniform and parabolic rifling should have been less than in the former series; as a matter of fact it is greater, but this may be accounted for by variations in the powder as previously suggested, as the suppression of a single round in each of the two guns would make the results in accordance with theory.

The coefficient of friction calculated from the uniform rifling gives $\mu_1 = 0{\cdot}133$.

The driving ring in this series was amply sufficient for rotative purposes, there not being even with the highest velocity obtained the slightest appearance of slip or undue wear.

In the fourth series the driving ring was of the Government pattern, but longer, and as is shown in section " C," and the results obtained were as given in the table.

Table V.—Results of Experiments with Driving Rings of Section " C."



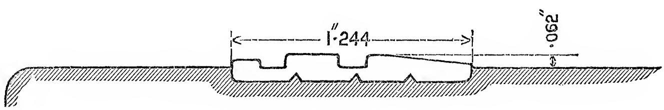
Nature of rifling.	Muzzle velocities.	Muzzle energies.	Mean muzzle velocities.	Mean muzzle energies.
	ft.-secs.	ft.-tons.	ft.-secs.	ft.-tons.
No twist............	2111 2114 2114	1417 1394 1394	2120	1402
Uniform twist.......	2092 2082 2088	1371 1358 1365	2087	1364
Parabolic rifling.....	2068 2066 2071	1339 1337 1343	2068	1340

The loss of velocity due to the uniform and parabolic rifling is, from these experiments, respectively 33 and 52 ft.-secs., and the loss of energy respectively 38 and 62 ft.-tons, or, expressed in percentages, 2·71 per cent. for the uniform rifling and 4·72 per cent. (the highest reached) for the parabolic rifling.

The value of μ_1, the coefficient of friction, calculated from the uniform rifling, is 0·359.

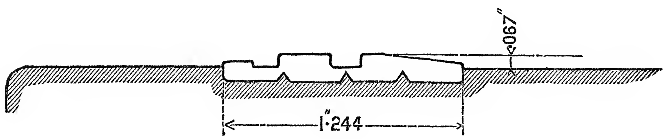
The fifth and sixth series were fired with driving bands of the Government pattern, but with radii successively slightly increased, as shown in the diagrams, and the results are given in the two following tables.

Table VI.—Results of Experiments with Driving Rings of Section "E."



Nature of rifling.	Muzzle velocities.	Muzzle energies.	Mean muzzle velocities.	Mean muzzle energies.
	ft.-secs.	ft.-tons.	ft.-secs.	ft.-tons.
No twist	2132 2124 2123	1418 1408 1406	2126	1411
Uniform rifling	2113 2115 2114	1398 1401 1399	2114	1399
Parabolic rifling	2099 2095 2081	1380 1375 1356	2092	1370

Table VII.—Result of Experiment with Driving Rings of Section "F."



Nature of rifling.	Muzzle velocities.	Muzzle energies.	Mean muzzle velocity.	Mean muzzle energy.
	ft.-secs.	ft.-tons.	ft.-secs.	ft.-tons.
No twist............	2112 2141 2141	1392 1430 1430	2131	1417
Uniform rifling	2104 2110 2124	1378 1384 1413	2113	1395
Parabolic rifling	2093 2099 2094	1372 1380 1373	2095	1375

From these two tables it will be seen that the loss of velocity due to the uniform and parabolic rifling is, in Table VI, 12 ft.-secs. and 64 ft.-secs. respectively; and in Table VII, 18 ft.-secs. and 36 ft.-secs. respectively; these velocities corresponding to losses of energy of 12 ft.-tons and 22 ft.-tons due to the uniform twist, and 41 ft.-tons and 42 ft.-tons, or about 3 per cent., due to the parabolic rifling. Calculated as before from the uniform rifling, the coefficients of friction are respectively 0·114 and 0·208.

Examining now with respect to the uniform rifling the whole of the series I have described, and observing that with this rifling the particular form or width of the driving ring would have but a very slight, if any, effect upon the loss of energy due to friction, it will be seen, from Table VIII, that the mean loss of energy amounts to 1·52 per cent. of the total energy corresponding to a mean coefficient of friction of 0·203, or, say, 0·2.

If, as I have pointed out, the loss of energy in the parabolic rifling was proportional to the pressure on the driving surfaces, the additional loss due to that rifling would be 0·74 per cent. The actual additional loss is, on the mean of the whole of the experiments, about three times as great, the mean loss due to parabolic rifling being, as shown by Table VIII, 3·78 per cent., and this considerable increment may be ascribed to the causes I have mentioned.

Table VIII.—Showing the percentage of Loss of Energy due to Friction in the various Series; showing also the Deduced Value of the Coefficient of Friction.

Series.	Loss due to uniform rifling.	Loss due to parabolic rifling.	Coefficient of friction.
	per cent.	per cent.	μ_1.
2	1·48	4·23	0·199
3	1·01	4·09	0·133
4	2·71	4·72	0·359
5	0·85	2·90	0·114
6	1·55	2·97	0·208
Means..	1·52	3·78	0·203

It may be worth while to mention that, in the groove formerly used in the Service, the angle between the normal to the driving surface and the radius could, without serious error, be taken as = 90°. In the groove adopted in the guns under consideration the mean value of δ is only about 34° 45′, and this difference in the driving angle increases the value of R, and, in consequence, the friction, by about 76 per cent. It would be interesting to make careful experiments to ascertain if there be any measurable difference in energy if an angle more nearly approaching to 90° were adopted. On account of the different length of the radius of gyration in the case of a solid shot and of a shell, the value of R is considerably affected when the latter projectile is fired. The difference of values is shown by the curves on p. 414.

In nearly all the countries of Europe an increasing twist is the form of rifling usually adopted; and, with such a consensus of practice, it must be assumed that some advantage is supposed to be gained by its use. There is, of course, with the parabolic rifling a less maximum pressure on the driving surfaces; but, as far as energy is concerned, both theory and the experiments I have detailed concur in showing that there is a distinct and very appreciable loss resulting from its employment. It is quite possible, although I am not acquainted with any carefully-conducted experiments on the point, that superior accuracy may be the advantage obtained; and if this were decidedly so, a loss of one or two per cent. of energy would not be, perhaps, a serious price to pay; but as, without any inconvenience, the question of accuracy could be easily settled, I trust that before very long this point also may be definitely determined.

It only remains to give the results obtained with cordite. At the time the experiments were made, I had only at my disposal a very limited amount of this explosive, and I was only able to fire one round in each of the guns, using the driving rings marked A, B, and C. As it would be useless to attempt to draw general conclusions from single rounds, and as in guns of the calibre experimented with the difference between the driving rings is not very marked, I have treated the series as if all the rounds had been fired with the same driving ring; the results are given in Table IX.

Table IX.—Results of Experiments with Cordite.

Nature of rifling.	Muzzle velocities.	Muzzle energies.	Mean muzzle velocities.	Mean muzzle energies.
	ft.-secs.	ft.-tons.	ft.-secs.	ft.-tons.
No twist	2177 2171 2194	1479 1476 1509	2181	1488
Uniform rifling	2160 2161 2172	1461 1462 1477	2164	1467
Parabolic rifling.......	2156 2152 2157	1455 1450 1457	2155	1454

From the cordite experiments, it follows that the loss of energy due to the uniform rifling is 21 ft.-tons, or 1·43 per cent., and to the parabolic rifling 34 ft.-tons, or 2·3 per cent.: the coefficient of friction deduced from the loss of energy with the uniform rifling being 0·199, or nearly the same value as was given in Table VIII.

III. "On the Thermal Conductivities of Crystals and other Bad Conductors." By CHARLES H. LEES, M.Sc., late Bishop Berkeley Fellow at the Owens College, Manchester. Communicated by Professor ARTHUR SCHUSTER, F.R.S. Received January 22, 1892.

(Abstract.)

The author commences by pointing out the great differences between the results obtained in 1879 by G. Forbes for the conductivities of quartz in different directions and those obtained in 1883 by Tuschmidt. He then refers to Kundt's discovery, that the metals stand in the same order as conductors, and as to the velocity of propagation of light through them, and mentions that his