While watching a female engaged in this process I observed a male dragonfly of the same species swoop past. The two rose together rapidly into the air: the male glided over the back of the female and gripped it by the neck with the clasping apparatus at the tip of its abdomen, in the position known to entomologists as *per collem*. The whole set of movements was so quick that it was difficult to observe. Whether the intervention of the male was to assist the female in the act of oviposition as is known to be the case with several other species, e.g. the blue dragonflies, or was with a view to the fertilisation of a further supply of eggs could not be ascertained, as the couple, after wheeling around overhead for a few moments, made off, and were soon lost to sight. It may be added that the females were strangely lacking in caution during their egg-laying, and were much more easily caught than is the case with these insects at ordinary moments.

NOTE ON *LIBELLULA QUADRIMACULATA*.

This very fine dragonfly, known by its robust abdomen and the four spots, one on each wing, was extremely common in the early part of June at the Bull Loch. On a hot day very many specimens could be observed flying over the water, settling on the rushes or careering over the heather, in which latter act, their large wings, vibrating so rapidly, gave them the appearance of flying in a mist. On the occasion of my visit there must have been several dozen of them on the wing.

SEISMOLOGY: OR THE THEORY OF EARTHQUAKES.

By Robert Ferguson, M.A.

[Read 7th March, 1911.]

EARTHQUAKE ZONES.

By placing on a map the places where earthquakes have been recorded, and shading the regions of most frequent recurrence darker than the others, the earthquake tracts of the historic period can be understood. In general they run along the lines of the volcanic cones of the earth; but there are some remarkable exceptions. A map thus shaded would show how very general these phenomena are. It is, doubtless, true that the earthquake is not recorded by savages, and that there are vast uninhabited tracts on the earth which can yield no histories; and it is important to observe that the blank spots on the map of earthquake distribution relate mainly to Greenland, Continental America north of 60° N., Asia north of the Arctic Circle, and most of Northern Europe and Asia. Africa, except slips to the north, by the Red Sea and on the extreme south, is a blank space, and so are Australia, except the sea coast on the east, and South America east of the 65th parallel of longitude W.

The tints denoting regions subject to occasional severe earthquakes will, of course, follow the lines of eruptive mountains, now more or less in activity, for distant volcanoes burst forth contemporaneously along great distances, and science advances the theory of deeply seated spaces where igneous rocks and gases and water are stored under immense pressure. The nearer the volcano the more severely felt will be the earthquake, and intermediate spaces will suffer more or less. I wish to draw your attention to the above view as I shall return to a consideration of it. An earthquake belt commences in Tierra del Fuego, and is marked along the west coast of South America, Central America, and Mexico. A line runs from Alaska to Kamtchatka and thence through Japan. Between these two belts is much of the United States, where occasional earthquakes are felt, and from this coast eastwards occupying the great valley and basin of the Mississippi, and all the States south of the lakes to the east coast is a tract never very severely shaken. An easterly prolongation of the South American belt exists at the Equator, and the earthquake belt of the West Indian Islands is continuous with it. On the other side of the great ocean is a belt comprising the great islands between Australia and the Asiatic mainland. These often-shaken islands, Java being an example, are extremely volcanic, and it is remarkable that they and one of the great earthquake districts of South America should be placed equatorially. The next belt of much intensity comprises the Italian Peninsula and the line of the Alps; and a second is intermediate and reaches along the flanks of the Himalayas to the Caucasus, thence by Syria to the Red Sea. The north of Spain mountain district stretches as an earthquake belt to Portugal, Lisbon, and in the Atlantic area to the Azores, Canaries, and Cape Verdi Islands. A northern belt connects Iceland to Scandinavia, and a Central European earthquake region is more or less in relation to the Alpine system. Far to the south at the Antipodes there is a belt from New Zealand northwards and southwards, and a branch to the Australian east coast. Finally, the North of Africa, the region of the Atlas, is in a belt which is continuous with that of the volcanic Atlantic Islands. There are probobly no spots on earth where the earthquake shock is not felt, but those mentioned feel it decidedly and sometimes severely.

EARTHQUAKE FREQUENCY OR ACTIVITY.

By the frequency of a phenomenon we mean the number of times it is repeated during a given interval of time. For

example, at Comrie, in Scotland, in 1844, during the month of January, 12 earthquakes were recorded, in the following month there were 4, while in the succeeding months the numbers became less. High frequency implies a high degree of seismic sensibility. After a district has reached a certain state of strain it is liable to yield, which it may do as a series of small displacements following each other at short intervals. The more general rule is that a district under strain yields with a sudden crash which is followed by a number of minor yieldings until seismic sensibility returns to its normal state.

One case may be likened to a bending stick which only crackles, while the other, which is the common occurrence, may be compared to a stick which gives way by snapping, and then crackles as it yields still further. The case which may compare to a stick which simply breaks and all is over, although not unknown, is comparatively rare. In Japan we have several excellent examples of the sudden yielding of a rocky mass, followed by a long series of after-shocks, indicating that disjointed strata were settling to a state of equilibrium. On these occasions it has been recorded by observation that after the first great blow had been delivered the frequency of the subsequent movements decreased at an increasing rate. From a table of observations made during the terrible disaster of October 28, 1891, we see that no less than 1132 shocks were recorded during the first 10 days. Between the 70th and 80th days the number had decreased to 87, while between the 150th and 160th only 13 were observed. The decrease, although fairly regular, was not absolutely so; now and then a shock, a little severer than its companions, would occur, and would be followed by its own little shocks. It seems desirable that these after-shocks should be examined to determine the existence or non-existence of a law governing their decrease in frequency. For the determination of this law let us take the case of a severe earthquake which had its centre near Gifu, in Japan. It can be shewn that the curve for the daily activity is practically satisfied by the equation $Y = \frac{519 \cdot 1}{X + 1 \cdot 535}$, while for the monthly activity it becomes $Y = \frac{16 \cdot 91}{X + 0 \cdot 397}$ where Y represents the number of shocks at any time X.

If it is allowed to apply these equations to intervals of time greater than those over which our observations have extended, then we have the means of determining the length of time that will be taken before the region will regain the same seismic quiescence that it had before the initial disturbance. Thus in the Mino-Owari earthquake, whose graph I have drawn, we see that there will be one weak shock per day, per week, per 15 days, &c., after intervals which are respectively 1, 4, 10 years.

THE FREQUENCY AND RECURRING PERIODS OF EARTHQUAKES.

It has been observed that in Japan the earthquakes observed have been more frequent at or about times of high wind, an observation which has been confirmed by many meteorologists. Darwin speaks of the earthquakes in certain parts of South America being regarded as indications of coming rain. It appears that there are two marked periods in every century when earthquakes are more numerous and intense, and one occurs at the middle and the other at the end of that lapse of time. The shocks of the greatest intensity are at the middle period, but it must be understood that in the intermediate time there may be shocks of great intensity. A great and most destructive shock may occur irrespective of time.

Very naturally inquiry has been made regarding the relation of earthquake frequency to the seasons of the year. In the northern hemisphere there are fewest earthquakes in the summer—the time of least activity being in May, June and July, while the greatest activity is shown in December and January, so that the preponderance of what is called seismic energy, the power to shake, is in the winter. These curious results of many observations are as interesting as those which show that there is a correspondence between the pressure of the atmosphere and earthquake phenomena.

Dr C. G. Knott, after much study of earthquake catalogues, has proved that there is a very decided winter period,

After a long period of rest we had a succession of large earthquakes in December, these, to some extent, confirming the winter-law. On December 13 there was one in West Africa which broke several cables, and on December 14 one in Scotland. On December 16 one occurred so far off as New Guinea. On December 17 one reached us from the West Indies. Next day one came from Java, and in less than two hours another was recorded, and it also had its origin in the West Indies. About 12 hours afterwards another large disturbance was recorded from we know not where. With the exception of the disturbance in Scotland they were all very large, and shook quite half the world. If seismic periodicity is considered with relation to Intensity, it seems that destructive earthquakes have chiefly occurred during the summer months, while for slight earthquakes both the annual and semi-annual periods are more marked.

C. G. Knott has shewn how loads due to the piling up of snow and barometrical pressures acting over large areas may possibly explain the winter frequency or annual periodicity of earthquakes, but unless we work with a catalogue extending over a large range of time, it is easy to see how this law, if not entirely lost, would at least be only feebly pronounced.

All seismic records up to the present have been of such a nature that investigators of periodicity, although they have classified earthquakes according to intensity, have not had the necessary materials enabling them to separate shocks which are the immediate results of orogenic causes from those which are brought into evidence by other influences.

ELECTRIC PHENOMENA.

It is recorded that during some of the Italian earthquakes the air was found to be in a very electric state and that electroscopes quickly shewed the presence of electricity in the air. The Ohio earthquakes of 1812 are said to have corroborated a belief held in America that electric discharges in the atmosphere and earthquakes are in inverse proportion to each other. References to luminous appearances in the heavens at or about the time of great earthquakes are very common. Even in truthful Britain we have many accounts of people receiving shocks in their bodies similar to electric shocks. Subsequent to the shock many people complained of nervous pains and hysterical affections similar to those who have been strongly electrified. Might I suggest that fear may have contributed to produce some of these effects.

It has been observed that the maximum frequency of electric phenomena occurs in the middle of October or a few days later, and the minimum about the first week in March. Attention was drawn to the connection between earthquakes and earth currents by Professor Ayrton, who observed that the Indian earthquake of 1872 was preceded by such strong earth currents on the previous evening in the land lines from Valencia to London that it was necessary to loop the lines in order to send messages. Examples of earthquakes accompanying or following earth currents are numerous. It does not follow, however, that these currents are contributory to the cause of earthquakes. It may be that the currents occurring at the time of an earth shaking might be caused by mechanical motion creating differences in contact between the earth and an earthplate, the result of which would be varying degrees of chemical action.

Not only do many suppose that earthquakes are accompanied by electrical phenomena, but since the time of Stukeley it has often been suggested that earthquakes are the immediate results of electrical discharges. A special pleader for those who seek to explain what they do not understand by an appeal to such phenomena, might call attention to the cubic miles of our atmosphere which are shaken at the time of a thunderstorm, and suggest several hypotheses which are not altogether devoid of facts for their support.

One suggestion is that a stratum of cloud raised to high potential might, by inductive stress, result in the collapse of a rocky crust underneath, which at the same time was in unstable equilibrium. Inasmuch as the maximum pull exerted between the two could not exceed that which would suffice to bring the cloud to the surface of the earth, it follows that the forces are too insignificant to be seriously considered. A second hypothesis is that beneath volcanic regions, watery steam may be escaping through fissures from regions of high pressure to those of lower pressure separated by insulating material. By such hydro-electric action electricity would be developed, and if we add to this condenser inductive action, conditions culminating in violent discharges would no doubt be reached. Although it would be difficult to deny the probability of the existence of electric action underground the facts that can be adduced to support the view that earthquakes result from the equalisation of electric potential are few in number and weak in character. Moreover, varied and numerous phenomena which we should expect to accompany such disturbances have never been observed, so that if we except the production of minor phenomena like the luminous appearance accompanying the friction of moving masses of rock any hypothesis connecting earthquakes and electricity appears to be quite untenable. It is clear from a study of earthquake catalogues and meteorological observations taken at the same time that electrical discharges contribute only to a small extent, if at all, to the cause of earthquakes.

Let us now turn to the consideration of the starting point of an earthquake, since, like everything else in the universe, it must have a starting point as well as a finishing point.

The region of commencing disturbance may be of considerable size. The sudden expansion of intensely heated water in an underground cavity, or explosions caused by chemical changes there, and the injection of lava—that is to say, rock dissolved under great pressure and heat by water—between the layers of the earth, would suddenly press outward on all sides upon the surrounding dense rocks. These could not move much in consequence of their being beneath some miles of similar substances, but each particle, on receiving the jar or outward momentary thrust, would communicate it to that immediately above it and so on to the surface. At the surface there are no other dense substances to restrain it, and the motion becomes evident. All along the line of particles there is a movement outward from the source and a return in the corresponding and opposite direction. Every spot around the underground cavity has its particles compressed and, as they are more or less elastic, there is a return to the original position, except in the case of the surface rocks. The shock which does the mischief is, of course, felt first on the surface, at the shortest distance from the focus. The last feeling of the shock is miles and miles away from this seismic vertical, and that is because the distance between such a locality and the focus is very great, and a great number of particles have to be moved one after the other along a slanting direction. Between the seismic vertical and the remote spot the shocks come up to the surface one after the other with great rapidity.

Starting from the focal space, the movement is along a succession of more and more slanting series of particles, and it reaches the surface at the same time in circles round the vertical point over the focus. By drawing a diagram on a map, of a number of circles becoming larger and larger round a common centre, whicb will represent the seismic vertical or centre where the shock was originally felt, each circle indicates the points of ground at which the movement was felt emerging simultaneously. The emergence of the movement from below becomes more and more oblique as the circles enlarge, and what is very important, the intensity of the movement diminishes in a corresponding manner. So rapidly do the particles move from below upwards in the successive circles, and so rapidly does each particle return to its place in the same direction that a wave-like movement is set up along the ground, moving on all sides from the seismic vertical. The rapidity of the movement can of course be measured by comparing clocks at different determinate points in the path. There is a remarkable difference between the rapidity of the passage of the movement through the earth to the surface and that of the movement along the surface caused by the succession of the former event. The first impetus given by the explosion or expansion within the confined underground space is not carried to the surface with its primary

rapidity and strength. The resistance of the rocks is considerable, and the meeting with soft and hard earth interferes. The movement diminishes rapidly towards the surface and, therefore, also the force, or the power to do mischief.

SEISMIC ELEMENTS WHICH ARE CALCULABLE.

In the mathematical illustrations which follow it is assumed that the to and fro motions experienced at the time of an earthquake are not forced vibrations, but are performed freely with a period dependent on the constitution of the matter in which they take place, and may be regarded as having a simple harmonic character.

Maximum velocity and maximum acceleration.

Let. $A =$ amplitude or half semi-vibration in m.ms.
$V =$ maxm. vel. in m.ms. per sec.
$F =$,, accn. in m.ms./sec^2.
$t =$ period of vibration in secs.

then $V = \frac{2\pi A}{t}$

and $F = \frac{V^2}{A} = \frac{4\pi^2 A}{t^2}$

By the maximum velocity is meant the highest velocity with which the vibrating particles moves.

By maxm. accn. is meant the greatest rapidity with which a vibrating particle changes its velocity of motion. This is popularly known as the jerk.

If a body like a column is standing freely on a surface that can be moved horizontally there is a certain initial rate of movement which will cause the body to overturn in a direction opposite to that of the movement of its base, and this quantity can be calculated from the dimensions of the body. Let the surface of the earth be undergoing at any instant an accn. of f ft./sec^2., let M be the mass of a column resting on the ground, y the height of its C.G. and X its horizontal distance from the edge about which it may be supposed to turn. There is a force F acting through the C.G. of the pillar tending to overturn it and given by

$$F = M.f.$$

the overturning movement being Fy, i.e., M. × M.f.y. This moment is opposed by the moment of the weight of the column Wx, and therefore when the column is on the point of overturning

$$Wx = Fy = Mfy = \frac{W}{g}.f.y$$

$$\text{i.e. } X = \frac{f.y.}{g}$$

$$,, \quad f = g.\frac{x}{y}$$

If f exceeds this value, the column may go over, if less, the column may stand.

FRACTURING OF COLUMNS.

Experiment has shewn that when a column stands vertically on a truck to which it is firmly attached and which is moved quickly back and forth, there is a certain rapidity of motion which causes the column to be fractured at or near the base; a still quicker motion is necessary to cause the broken column to fall. Calling the acceleration of the truck which is necessary for the column to fracture a then it can be shewn that

$$a = \frac{1}{6}\frac{gFAB}{fW}$$

where F = force of cohesion of the material, or the force per unit area that must be applied to produce fracture.

A = area of base fractured.
B = thickness of column.
f = height of C.G. of column above the fractured base.
W = wt. of portion of pillar broken off.

F, of course, has different values for different materials which can be obtained by experiment.

From this formula we can get a second shewing the height to which a wall may be built capable of resisting an accn. of value a, it may be written

$$X = \sqrt{\frac{FBg}{3as}} \quad [S = \text{wt. of unit vol. of brick}].$$

where X = ht. of wall.

From this last formula, assuming the greatest acceleration we may expect in a district to be 1000 m.ms. per sec., we can determine the height to which a column or wall of given section, and made of materials of a known tensile strength,

may be carried above its foundations and be just able to withstand the given motion. For example, a column of brick two feet square, having a value for F of 15lbs. per square inch, would just be on the point of fracturing if it was 11ft. 7ins. in height.

THE FRACTURING OF BRIDGE SUPPORTS.

Since yielding first shows itself at the base of a column it is evidently necessary that its lower section should be of greater dimensions than that which comes above it, or to extend our idea, every horizontal section of the structure should be sufficiently strong to resist the effects of the inertia of its superstructure. In a square column, for example, where y = half the dimensions of any given section whose distance from the top is X, then for a to remain constant in our original equation

$$X^2 = 10\frac{gF}{as}.y$$

If the column have a circular section

$$X^2 = 7\tfrac{1}{2}\frac{gF}{as}.y$$

If it is rectangular

$$X^2 = 4\frac{gF}{as}.y$$

From these it is clear that with the same dimensions of base and height the strongest column is one with a square section.

As an illustration, for a column with a square section, suppose

a = 1000 m.m. per sec^2.
F = 5 lbs. per sq. in.
S = ·0608 per C. in.

then with x and y expressed in ins.,

$$y^2 = 8100x$$

The outline of this column is parabolic in form. In practice its upper portion would naturally be cut off. Some engineers listening to the dicta of mathematical physics have recently built bridge supports of this form for railways in Japan, and it has been found that they have a greater resisting power against earthquake forces than the ordinary piers.

ON THE PROBABLE CHARACTER OF EARTHQUAKE MOVEMENT.

If it is assumed that the crust of the earth has the character of an elastic solid, then from an earthquake centrum two types of waves may emanate. In one of these the direction of vibration of a particle is parallel to the direction of propagation of the wave, whilst in the other case it is transverse to such a direction, or so far as this character is concerned it is like a light-ray. These two types of waves, which are respectively known as condensational and distortional waves, are propagated with different velocities which depend on certain elastic properties of the material.

The velocity in the condensational wave is $\sqrt{m/p}$, whilst that in the distortional is $\sqrt{n/p}$, where p is the density of the material, n the modulus of rigidity or power of resistance to distortion, and m a modulus which depends on the modulus of rigidity and the bulk modulus or resistance to compression k, and is equal to $k + \frac{4}{3}n$. k and n can be determined experimentally. They have been determined for granite, marble, slate, &c.,

$$\text{e.g. } p = 3$$
$$\text{Rigidity } n = 1 \cdot 5 \times 10^{11} \text{ C.G.S. units.}$$
$$\text{Ratio of wave moduli } \frac{m}{n} = 3$$

with these numbers the velocity of a distortional wave would be 2·235 K m./sec , while the condensational wave would have a value not quite double this amount. These values agree fairly well with the values obtained by observation.

Let us now consider briefly the emotional and moral effects of earthquakes on the inhabitants of a country. We shall do this by a sort of introspection. A new-comer to an earthquake country would, no doubt, express surprise that the small disturbances he experiences should create alarm, but after frequent repetitions with, sooner or later, experiences of shakings that are moderately severe, the feeling of indifference, if not replaced by one of alarm, would, we may assume, give way to one of anxious enquiry. When a slight vibration commences we do not know whether it will die out as it has

begun, or whether it will culminate in a shock of unknown magnitude, so that the smallest tremors will often cause anxiety about what may happen next. A disastrous shock will throw the weaker members of a community into a state of terror or hysterics, and at every little shock, perhaps, for the remainder of their lives, they will either be so far unnerved that they do not move, or else seized with alarm they will seek a place of safety.

An appeal to statistics shews us that calamities which have occurred in earthquake countries have, in all likelihood, been sufficient to shake ideas concerning permanency, and to create feelings of carelessness for the morrow.

In Japan alone on October 28, 1891, in 30 secs., the country lost from 30 to 50 million dollars, 9960 people were killed, and the wounded numbered 19,994; 128,750 houses, without counting temples, factories, &c., were levelled with the plain, landslips stripped the mountains of their forests, valleys were compressed, lakes were formed, the strongest engineering structures gave way, and the country was left fractured, fissured and tossed into a sea of waves.

We see in the Japanese myths explaining the origin of earthquakes, and in the drawings of the fantastic monsters which create these disturbances direct effects on the imagination. In the festivals at temples to commemorate these great disasters, in the prayers which have been formulated, in the repeal of taxes to appease an angry deity, in the sermons which have been preached, and in the form of mountain worship, we see how religion and morality have been influenced by seismic and volcanic phenomena. When a European community is overtaken by a disaster similar to those which frequently happen in Japan, women become hysterical, men lose their nerves and act as if they had lost their reason. On one of these occasions we learn that the result of this nervous excitement showed itself in the form of tetanus, spinal and other troubles, rather than in any general mental paralysis. A Japanese is not nervous before a public audience or the surgeon's knife, nor does he show unreasonable excitement at the time of a great earthquake. If, from time to time, in Scotland, or in any other European country, towns were levelled, coasts were inundated, mountains flowed like water, whilst everything that we regard as permanent was repeatedly reduced to ruin, it would seem natural that ideas of permanency would be destroyed, a carelessness for the future might be engendered, and a timidity might be established among the weaker members of a community which would handicap them in the struggle for existence. The general temperament of a nation is no doubt due to its environment, and it is not unreasonable to suppose that serenity of demeanour and carelessness of the future may hold some relationship to repeated exhibitions of seismic and volcanic energy.

Report of the Council of the Buteshire Natural History Society to the Fifth Annual General Meeting of the Society, held in the Bute Museum, Battery Place, Rothesay, on Tuesday, 29th November, 1910, at 8 p.m.

The programme arranged for last winter was duly carried out, meetings of the society having been held on 7th December, 11th January, 1st, 8th, and 22nd February, and 4th March.

The stormy weather of last winter and the General Election somewhat interfered with the attendance at the meetings, but, on the whole, the attendance was good, the average being about 26. The papers contributed were printed as the Third Volume of the Society's Transactions, and a copy sent to each member. The Meteorological Observations made by Mr D. Penney, at Glenburn, as tabulated with the assistance of various members, are included in the Transactions.

A programme of meetings for the ensuing winter and spring has been arranged, and is in the hands of the members.

Examinations for young people in simple natural history were again carried out. The first set of examination questions was revised and reprinted, and the examinations were conducted in the same manner as those of the previous year. There was again a large entry, and the questions were extremely well answered, thirty-six gaining over 80 per cent. of marks. The School Board of Rothesay have again recognised the educational advantages afforded by the Society by renewing their grant of £5 5s to the funds.