XLIII. An attempt towards a theory of the resistance experienced by two and four-wheeled carriages on different kinds of roads; and to determine the circumstances under which the one are preferable to the other

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To cite this article: Nicholas Fuss (1802) XLIII. An attempt towards a theory of the resistance experienced by two and four-wheeled carriages on different kinds of roads; and to determine the circumstances under which the one are preferable to the other, Philosophical Magazine Series 1, 13:51, 257-266, DOI: 10.1080/14786440208676124

To link to this article: http://dx.doi.org/10.1080/14786440208676124

Published online: 18 May 2009.

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For good figures of the C. cancellatus, Micheli may be referred to, and for the two latter, Curtis's Fl. Lond. and Sowerby's English Fungi, called in both publications Phallus.

I am not aware that any other Fungus will arrange with the above three species, although some have been placed under the genus Phallus, by Linnaeus and other botanists, which have very little agreement with the P. impudicus and P. caninus of those authors.

XLIII. An Attempt towards a Theory of the Resistance experienced by two and four-wheeled Carriages on different Kinds of Roads; and to determine the Circumstances under which the one are preferable to the other. By Nicholas Fuss, Professor of the higher Mathematics at Petersburgh, Member of the Imperial Academy of Sciences, &c.

[Continued from p. 122.]

SECOND DIVISION.

Of the Resistance on solid and uneven Roads.

I. Four-wheeled Carriages.

Section 19.

If the road AB, Plate II. fig. 4. be naturally rough and stony, or paved artificially, or covered in some places with trees laid across it, new impediments arise from these inequalities, and the resistance found in the preceding division, section 9, which takes place here also, acquires an increase, which is determined in the following manner:

Let the wheel touch in G and G' two equally large and solid inequalities of the road, and for the fore-wheels let the angle GOG' = 2ϕ, but for the hind-wheels GOG' = ϕ. Now as a part of the moving power OV, which we shall call OU = K, must be employed to overcome a part of the power of gravity acting in a direction perpendicular to AB, which is (P + p) cos. ϕ, and to raise the fore-axle together with its part of the load over the fixed point G, the momentum of these powers OU, GU and OR, GR must be equal to each other; that is, KGO cos. ϕ = (P + p) cos. ϕ, GO sin. ϕ; so that the increase of resistance arising from this impediment will be for the fore-wheels K = (P + p) cos. ϕ tang. ϕ. A similar increase will be found for the hind-wheels = (P + p') cos. ϕ tang. ϕ. Consequently the whole resistance on roads of the second class for four-wheeled carriages is:

\[ R = \frac{1}{2} (m + n) \lambda P \cos. \alpha + (P + p + p') \sin. \alpha + \frac{1}{2} (P + p) \cos. \alpha \tan. \phi + \frac{1}{2} (P + p') \cos. \alpha \tan. \phi \]
II. Two-wheeled Carriages.

Section 20.

The resistance found in the preceding division, section 12, for carriages of this kind, acquires here an increase, which, if we make the angle $GOG' = 2\omega$, will be found in the same manner as in the preceding section $= (P + \pi) \cos \alpha \tan \omega$.

The whole resistance for two-wheeled carriages on roads of the second class will therefore be expressed as follows:

$$R' = \mu \lambda P \cos \alpha + (P + \pi) \sin \alpha + (P + \pi) \cos \alpha \tan \omega$$

III. Comparison of the two Kinds of Carriages.

Section 21.

If the comparison be made in general according to the five different points of view mentioned in the 16th section, it will be found that four-wheeled carriages are preferable to two-wheeled when any of the five following conditions take place:

1st, \[ \frac{m+n-2}{2} < \frac{(eP + \pi - p - \rho') \tan \alpha + (P + \pi) \tan \omega}{\frac{\lambda P}{\tan \alpha}} \]

2nd, $\phi + \phi' - \pi < \frac{eP - (m+n-2\mu) \lambda P + (P + \pi) \tan \omega}{\tan \alpha}$

3rd, $\phi + \phi' - \pi < \frac{\pi - (P + \pi) \tan \omega}{\tan \alpha}$

4th, $\varepsilon > \frac{(m+n-2\mu) \lambda P + (P + \pi) \tan \alpha + (\frac{1}{2} P + \pi)}{\frac{P \tan \alpha}{\tan \phi + (\frac{1}{2} P + \pi) \tan \omega - (P + \pi) \tan \omega}}$

5th, $\tan \alpha > \frac{(m+n-2\mu) \lambda P + (\frac{1}{2} P + \pi) \tan \phi + (\frac{1}{2} P + \pi) \tan \omega - (P + \pi) \tan \omega}{\frac{eP + \pi - p - \rho'}{\tan \phi + (\frac{1}{2} P + \pi) \tan \omega - (P + \pi) \tan \omega}}$

**Example I.**

Section 22.

Let the road be composed of round pieces of timber six inches in diameter laid across it, and let $\alpha = 0$. Let the mean diameter of the fore and hind axle-trees of the four-wheeled carriages be $3\frac{1}{4}$ inches; that of the axles of the two-wheeled carriages $3\frac{1}{4}$; and the diameter of the wheels in the same
fame order, 26, 39, and 45 inches; so that \( m = \frac{1}{3} \), \( n = \frac{1}{2} \), and \( \mu = \frac{1}{3} \): also, let \( P = 1000 \) lib., \( \rho = 74 \) lib., \( \rho' = 106 \) lib., and \( \pi = 130 \) lib.; and let the coefficient of the friction be \( \lambda = \frac{3}{5} \). In the last place, as \( TG = TF = 3 \) inches, we shall have for the wheels in the above order \( TO = 16, \frac{1}{3} \) and \( \frac{1}{3} \) inches, and because \( \sin TOF = \frac{TF}{TO} \); the angle \( TOF \), that is to say, \( \phi = 10^\circ 48' \); \( \psi = 7^\circ 40' \); \( \omega = 6^\circ 45' \). From these elements we obtain,

\[ \frac{1}{2} (m + n) \lambda P = 23'148 \]
\[ (\frac{1}{2} P + \rho) \tan \phi = 109'496 \]
\[ (\frac{1}{3} P + \rho') \tan \psi = 81'575 \]

\[ R = 214'219 \]
\[ \mu \lambda P = 18'518 \]
\[ (P + \pi) \tan \omega = 133'744 \]

\[ R' = 152'262 \]

For a horse, then, whose strength \( M = 400 \) lib. and velocity \( G = 13 \) feet on such a road, we have \( g = 3'484 \) feet, and \( g' = 4'979 \) feet in a second.

It might be conjectured that four-wheeled carriages, the fore-wheels being so small, would experience a resistance considerably greater than the two-wheeled. Were \( m = n = \frac{1}{3} \), and \( \rho = \rho' = 106 \), we should have \( R = 181'669 \), and \( g = 4'238 \).

**Example II.**

Section 23.

Let the road be steep and composed of stones, the angle of elevation being \( \alpha = 14^\circ \), and let the pavement be of such a nature, that the distance between the points of contact \( G, G' = 3 \) inches, consequently the angle \( \phi = 5^\circ 45' \); \( \psi = 4^\circ 6' \); and \( \omega = 3^\circ 49' \). Let the burden be \( P = 1800 \) lib., the mean diameter of the axle-trees of the fore-wheels = \( 3\frac{1}{2} \) inches, of the hind-wheels \( 3\frac{1}{2} \) inches, that of the two-wheeled carriages \( 3\frac{1}{2} \) inches; let the diameter of the wheels in the same order be \( 30, 42 \), and \( 45 \) inches; so that \( m = \frac{1}{3} \), \( n = \frac{1}{2} \), and \( \mu = \frac{1}{3} \). The weight of the wheels we shall suppose to be \( \rho = 80 \) lib. \( \rho' = 110 \) lib., and \( \pi = 120 \) lib. In the last place, let \( \lambda = \frac{3}{5} \), and \( \epsilon = \frac{1}{3} \). Hence we obtain

\[ \frac{1}{3} (m + n) \lambda P \cos \alpha = 33'960 \]
\[ (P + \rho + \rho') \sin \alpha = 481'425 \]
\[ (\frac{1}{3} P + \rho) \cos \alpha \tan \phi = 95'750 \]
\[ (\frac{1}{3} P + \rho') \cos \alpha \tan \psi = 70'247 \]

\[ R = 681'382 \]

\[ \mu \lambda P \]
On the Resistance experienced by

\[ \mu \lambda P \cos \alpha = 29.109 \]
\[ (P + \varepsilon P + \pi) \sin \alpha = 482.634 \]
\[ (P + \pi) \cos \alpha \tan \omega = 124.282 \]

\[ R' = 636.025 \]

Three horses, therefore, whose strength is \( M = 1200 \) lib. and their velocity on this kind of road \( G = 10 \) feet, could draw the burden \( P = 1800 \) lib. on a four-wheeled carriage at the rate of \( g = 2.47 \) feet per second, and on a two-wheeled carriage about \( g' = 2.72 \) feet.

Section 24.

On a horizontal road of the above nature we shall have for the same carriages and load \( R = 206.08 \) and \( R' = 158.09 \). For a horse therefore whose strength \( M = 400 \) lib., and velocity on this horizontal road \( G = 15 \) feet, we shall have \( g = 4.23 \) and \( g' = 5.58 \) feet.

Third Division.

Section 25.

If the surface of the road be composed of soft sand, slate, earth, clay, dirt, &c. the wheels will sink into it, and the depth to which they sink will be greater the softer and more fluid the matter is of which the road consists.

Now as the increase of resistance depends on the depth to which the wheels sink, and as this depth depends on the nature of the matter, that is to say, its hydrostatic power, which can be determined only by experiment, I shall assume that a prismatic body the thickness of which is \( d \) square inches and its weight \( g \) lib. sinks merely by its gravity \( c \) inches deep in the fluid matter, or displaces \( ddc \) cubic inches of it before it comes into equilibrium; this matter, then, in regard to hydrostatic power produces the same effect as would be produced by an aqueous fluid a cubic foot of which weighs \( \frac{1237}{ddc} \) lib.

A load \( Q \), Pl. II. fig. 5. will press down both wheels on the axis \( O \) till they have displaced \( \frac{ddcQ}{g} \) cubic inches of the fluid matter. If \( FR \) be the depth to which the wheels sink, and \( \pi' \) the circumference of a circle whose diameter = 1, the superficial content of the sunken segment \( GFG'R \) is \( GO^2 \left( \frac{\pi' \cdot \overline{GOR}}{180^\circ} \right) = \frac{1}{2} \sin \overline{GOG} \). And if the fellies be
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If we make the angle $\text{GOR} = \beta$, it will be found in the

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same

\[ \begin{align*}
    \text{R} &= \frac{1}{2} (m + n) \times P \cos. \alpha + (P + P + P') \sin. \alpha \\
    &\quad + \cos. \alpha \sin. \beta \left[ (P + p) \tan. \xi + (\frac{1}{2} P + P') \tan. \eta \right]
\end{align*} \]

II. Two-Wheeled Carriages.

Section 27.
On the Resistance experienced by

fame manner as in the preceding section, that the increase of
resistance on roads of this kind is \((P + \pi) \cos \alpha \sin \beta \tan \gamma\); and the whole resistance for two-wheeled carriages
will be,

\[
R' = \mu \times P \cos \alpha + (P + \pi P + \pi) \sin \alpha + (P + \pi) \cos \alpha, \sin \pi, \tan \gamma.
\]

III. Observations on these Formulae R and R'.

Section 28.

These expressions for R and R' as above found contain, as
we shall soon see, a complete solution of the problem, as
they answer for all the three classes of roads.

1st, For solid and even roads where \(\xi = \phi, \eta = \psi, \gamma = \phi,\) and \(\theta = 90^\circ\), they give for R and R' the same values as those
found for resistance in the first division.

2d, For solid and uneven roads where \(\xi = \psi, \eta = \delta, \gamma = \omega,\) and \(\theta = 90^\circ\), we have the same values for R and R' as
those found in the second division.

3d, For roads with standing water on a solid bottom
(which, however, must not reach to the spokes, because in
this case the resistance must be determined in another man-
er), where \(\theta = \phi,\) we shall have R and R' as in the first di-
vision. In this case, no perceptible increase of resistance arises: on the other hand, on such roads G and consequently
V is less than on roads of the first class.

4th, When one of the angles \(\xi, \eta, \) or \(\gamma,\) is a right angle; that
is, when P is so great that the wheels sink up to the axle in
the soft surface, the resistance becomes infinitely great, except
in that case only where the fluid is very thin, and \(\theta = \phi;\) in
which case instead of an infinitely great resistance we shall
have only an indefinite increase \(= \infty,\) which cannot be
determined from the grounds mentioned in the third observa-
tion.

In the last place, it is to be observed in regard to these ex-
pressions,

5th, That when the soft tender surface has a solid bottom,
and is not so deep that the wheels can penetrate into it ac-
cording to the laws of hydrostatics, the angle GOR must not
be determined according to the absolute sinking, but according
to the depth of the solid bottom.

6th, That for less fluid matters, such as moist sand, moist
earth, stilly clay, dirt, &c. in the expression for the resistance
of four-wheeled carriages, R the last member for the hind-
wheels \((\pi P + \phi') \cos \alpha, \sin \beta, \tan \eta,\) vanishes, because
these wheels run in the ruts formed by the fore-wheels.
IV. Comparison between the two Kinds of Carriages.

Section 29.

On roads of this class, four-wheeled carriages are to be preferred to two-wheeled, when one of the five following conditions takes place:

1st, \[ \frac{m+n-2\mu}{2} < \left( \frac{P+\pi-r-r'}{t} \right) \alpha + \text{fin.} \beta \left( \frac{(P+\pi)}{t} \right) \Sigma \left( \frac{P+\pi}{t} \right) \]

\[ \lambda \left( P + r \right) \text{tang.} \xi - \left( \frac{1}{2} P + r' \right) \text{tang.} \eta \]

2nd, \[ \rho + \rho - \pi < \epsilon \left( \frac{m+n-2\mu}{2} \right) \frac{1}{2} \lambda P + \text{fin.} \beta \left( \frac{(P+\pi)}{t} \right) \Sigma \left( \frac{P+\pi}{t} \right) \]

\[ \frac{\text{tang.} \alpha}{\lambda \left( P + r \right)} \text{tang.} \xi - \left( \frac{1}{2} P + r' \right) \text{tang.} \eta \]

3rd, \[ P > (\rho + \rho' - \pi) \text{tang.} \xi + \left( \frac{1}{2} P + \rho' \right) \text{tang.} \eta - (P + \pi) \text{tang.} \xi \]

\[ \left( \frac{m+n-2\mu}{2} \right) \frac{1}{2} \lambda P + (\rho + \rho' - \pi) \text{tang.} \alpha + \text{fin.} \beta \]

4th, \[ \epsilon \left( \frac{m+n-2\mu}{2} \right) \frac{1}{2} \lambda P + (\rho + \rho' - \pi) \text{tang.} \alpha \]

\[ \frac{P + (\rho + \rho') \text{tang.} \eta - (P + \pi) \text{tang.} \xi}{P + (\rho + \rho') \text{tang.} \eta - (P + \pi) \text{tang.} \xi} \]

5th, \[ \text{Tang.} \alpha > \frac{\left( \frac{1}{2} P + \rho' \right) \text{tang.} \eta - (P + \pi) \text{tang.} \xi}{\frac{1}{2} P + \rho' - \rho} \]

\[ \frac{\epsilon \left( \frac{m+n-2\mu}{2} \right) \frac{1}{2} \lambda P + \text{fin.} \beta \left( \frac{1}{2} P + \rho' \right) \text{tang.} \xi}{\epsilon \left( \frac{m+n-2\mu}{2} \right) \frac{1}{2} \lambda P + \text{fin.} \beta \left( \frac{1}{2} P + \rho' \right) \text{tang.} \xi} \]

That these five conditions are general, and contain the conditions found for the two classes before treated, section 16 and section 17, it is superfluous to mention, after what has been said in the first two remarks of the preceding section.

Application to some determinate Cases.

EXAMPLE I.

Section 30.

I poured very dry coarse red sand, Pl. II. fig. 6. after I had found the angle \( \beta = 30^\circ 42' \) (that is to say, \( AB = 16 \) inches and \( CD = 4^\frac{1}{2} \) inches), into a vessel, and, smoothing the surface of it after each experiment by shaking it so as to obtain the same degree of softness, I took a steel rod weighing 5 lb., which I had caused to be constructed for magnetic experiments, and which was just an inch square, and pushed it several times into the sand in a gentle manner, to prevent the acquired velocity from making it sink deeper than the equilibrium sought for. Sixteen experiments of this kind, in which the greatest difference did not amount to half a line, gave
gave as a medium of the sinking \( \frac{x}{4} \) inches, so that \( ddc = \frac{x^2}{4} \) inches, and \( q = 5 \) lib.

Let the road consist of such soft sand; let the inclination \( \alpha = 4^\circ \); the load \( P = 1200 \) lib., the weight of the wheels \( p = 84 \) lib. \( p' = 110 \) lib., \( x = 132 \) lib.; their diameter in the same order as before, \( 31\frac{1}{2}, 42 \) and \( 49 \) inches. Also let \( m = \frac{1}{3}, n = \frac{1}{3}, \mu = \frac{1}{2}, \lambda = \frac{1}{2}; \) OS = \( 2\frac{1}{2} \) feet and \( OI = 12 \) feet; so that \( e = \frac{1}{6} \). In the last place, let \( b = 3 \) inches, consequently,

\[
\begin{align*}
\frac{\pi \xi}{90^\circ} & \quad \text{fin.} \ 2 \xi = 0.05361, \ \text{and} \ \xi = 19^\circ 47' \\
\frac{\pi \eta}{90^\circ} & \quad \text{fin.} \ 2 \eta = 0.03130, \ \text{and} \ \eta = 16^\circ 30' \\
\frac{\pi \phi}{90^\circ} & \quad \text{fin.} \ 2 \phi = 0.04315, \ \text{and} \ \phi = 18^\circ 23' \\
\left(\frac{1}{2}(m + n) P \cos \alpha \right) & \quad = 23.276 \\
(P + p + p') \sin \alpha & \quad = 97.242 \\
\left(\frac{1}{2} P + p\right) \cos \beta, \ \text{tan} \ 2 \xi & \quad = 125.303 \\
\left(\frac{1}{2} P + p\right) \cos \beta, \ \text{tan} \ \beta, \ \text{tan} \ \alpha & \quad = 107.112 \\
R & \quad = 352.933 \\
\mu \lambda P \cos \alpha & \quad = 17.101 \\
(P + \pi P + \pi) \sin \alpha & \quad = 94.311 \\
(P + \pi) \cos \alpha, \ \text{tan} \ \beta, \ \text{tan} \ \alpha & \quad = 225.450 \\
336.862
\end{align*}
\]

If we suppose for two horses \( M = 800 \) and \( G = 11 \) feet, we shall have \( g = 3.696 \) feet and \( g' = 3.861 \) feet in a second.

However well the two-wheeled carriages may be constructed, however small the burden, the inclination of the road, and the height of the centre of gravity, the resistance is only a little less than for four-wheeled carriages. To show how much depends on the proportion of the wheels, and particularly in regard to carriages of this kind, I shall in the following examples change only the wheels of the two-wheeled carriages.

**Example II.**

**Section 31.**

Let every thing be as before, only for the two-wheeled carriages let \( GO = 16 \) inches, \( x = 85 \) lib., and \( \mu = \frac{1}{3} \); therefore \( \theta = 24^\circ 15' \), and

\[
\begin{align*}
\mu \lambda P \cos \alpha & \quad = 26.186 \\
(P + \pi P + \pi) \sin \alpha & \quad = 91.032 \\
(P + \pi) \cos \alpha, \ \text{tan} \ \beta, \ \text{tan} \ \alpha & \quad = \frac{204.808}{412.026} \\
\end{align*}
\]

Therefore
two and four-wheeled Carriages.

Therefore we shall have as before \( R = 352'933 \text{ lib.} \), but \( R' = 412'026 \text{ lib.} \); consequently \( g = 3'696 \text{ feet, and } g' = 3'102 \text{ feet.} \)

**Example III.**

*Section 32.*

After a series of similar experiments with somewhat coarser and very moist red sand, I found \( \beta = 43° 10' \), and \( e = \frac{1}{2} \text{ inch at a medium.} \) But it is to be observed that the impressions made by immerging the steel rod did not disappear as from the above dry sand, but remained after it was drawn out; and therefore after each experiment I was obliged to make the sand even and soft by shaking it, and to render its surface smooth by a slight pressure proportioned to the exact measurement of the depth; by which means it lost a little of its natural softness. When I placed the rod again in the remaining impression it did not become deeper. Hence follows what we are taught by experience in general in regard to moist sand, moist earth, thick mud, &c. that the hind-wheels when they revolve in the ruts formed by the fore-wheels do not make them deeper, and consequently experience no resistance from sinking down; so that in the value of \( R \), section 26, found for four-wheeled carriages, in such cases the last member \( \left( \frac{1}{2} P + p \right) \cos \alpha, \sin \beta, \tan \gamma \) vanishes.

Let us suppose then, as in the first example, section 30, that the angle \( \alpha = 4° \) the weight of the wheels, \( p = 84 \text{ lib.}, \) \( p' = 110 \text{ lib.}, \) \( \pi = 132 \text{ lib.}; \) and their semidiameter in the same order, \( GO = 15\frac{3}{4}, 21, 24\frac{1}{2} \text{ inches, and } b = 3 \text{ inches;} \) also let \( m = \frac{1}{5}, \) \( n = \frac{1}{4}, \mu = \frac{1}{3}, \lambda = \frac{1}{2}, \) \( e = \frac{1}{6}, \) and \( g = 5 \text{ lib.} \) If the load be \( P = 900 \text{ lib}, \) and \( dd = \frac{1}{2} \text{ cubic inches,} \) we shall have

\[
\begin{align*}
\frac{\pi}{54} & = \sin 2\xi = 0'05980, \text{ and } \xi = 20° 32' \\
\frac{\pi}{18} & = \sin 2\eta = 0'03527, \text{ and } \eta = 17° 10' \\
\frac{\pi}{90} & = \sin 2\eta = 0'04776, \text{ and } \eta = 19° 10' \\
\frac{1}{2} (m + n) \lambda P \cos \alpha & = 17'457 \\
(P + p' + p') \sin \alpha & = 76'313 \\
\left( \frac{1}{2} P + p \right) \cos \alpha, \sin \beta, \tan \xi & = 136'878 \\
R & = 230'648 \\
\mu \lambda P \cos \alpha & = 12'826 \\
(P + \xi P + \pi) \sin \alpha & = 73'035 \\
(P + \pi) \cos \alpha, \sin \beta, \tan \gamma & = 243'414 \\
R' & = 329'275
\end{align*}
\]
Some Account of Edward Jenner, M.D.

If for a horse on this road $M = 400$ lib. and $G = 12\frac{1}{2}$ feet, we shall have $g = 3'012$ and $g' = 1'162$ feet in a second.

Also if the hind-wheels do not run exactly in the ruts formed by the fore-wheels, and if the member $(P + p')\cos. \alpha, \sin. \beta, \tan. \eta = 118'389$, cannot be entirely omitted, we shall still have $R < R'$ even when only the fourth part of it vanishes.

[To be continued.]

XLIV. Some Account of Edward Jenner, M.D.

This gentleman, who has distinguished himself so much in the annals of medicine by bringing forward the vaccine inoculation to public notice, and who has been thought worthy of national remuneration on that account, is a son of the Rev. Stephen Jenner, formerly vicar of Berkley in Gloucestershire, a man highly respected by all those who had the pleasure of his acquaintance. Edward was born about the year 1749, and received his education at Cirencester in the same county. Having made a considerable progress in classical learning, and shewing an early attachment to the study of physic, he was placed under the care of Mr. Ludlow, an eminent surgeon at Sodbury, a large market-town between Bristol and Wotton under Edge. After remaining with this gentleman some time, during which he applied with assiduity, and made rapid improvement, he repaired to London to complete his medical education, and became a house-pupil to the celebrated John Hunter. In this situation he continued two years, and availed himself with great success of the instruction of so able a master. At the expiration of this period he removed to Berkley, where he commenced practice, and met with considerable encouragement. In the mean time he still kept up his intimacy with Mr. Hunter by a regular correspondence; and the frequent mention which Mr. Hunter has made of him in his works is a striking instance of the favourable opinion which he entertained of his abilities. An ingenious paper on the natural history of the cuckow, in a letter addressed to Mr. Hunter, was communicated by him to the Royal Society, and was inserted in the Philosophical Transactions for 1788. Several other papers of his on intricate subjects in natural history were published about the same time. In 1778 he married Miss Catherine Kingscote of Kingscote in Gloucestershire, by whom he...