A

TREATISE

ON

RAILWAY IMPROVEMENTS,

EXPLANATORY OF THE CHIEF

DIFFICULTIES AND INCONVENIENCES

WHICH AT PRESENT ATTEND THE GENERAL ADOPTION OF

RAILWAYS,

AND

THE MEANS BY WHICH THESE OBJECTIONS MAY BE OVERCOME;

AS PROVED BY A SERIES OF

INTERESTING EXPERIMENTS.

TO WHICH ARE ADDED,

VARIOUS REMARKS ON THE OPERATION AND EFFECT

OF

LOCOMOTIVE POWER.

BY RICHARD BADNALL, ESQ.

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ON

RAILWAY IMPROVEMENTS,

&c. &c.

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(Successor to B. M'Millan),
BOW-STREET, COVENT-GARDEN.

TO

E. J. LITTLETON, Esq. M. P.

TEDDESLEY PARK, STAFFORDSHIRE.

MY DEAR SIR,

As a very humble token of my esteem for your high Character and Public Worth, and for the valuable Services which, for a period of Twenty Years, you have rendered, as its Independent Representative in Parliament, my Native County, permit me to dedicate to you the following pages.

I have the Honor to be,

MY DEAR SIR,

Very faithfully yours,

RICHARD BADNALL.

Manchester,
March 1, 1833.

PREFACE.

The only apology which I think it necessary to offer, in submitting the following pages to public judgment, is to those men of science who may deem that I have entered too minutely into the explanation of some mechanical laws, which explanation must appear to them entirely useless and unnecessary: but, conceiving it probable, at this particular period, when Railways form a subject of universal interest and conversation, that this short Treatise may fall into the hands of many altogether unacquainted with mechanics, I hope I shall be pardoned for having extended my observations, especially on the laws of friction and gravity, farther than I should otherwise have done. My anxiety is, to be understood by all; and my earnest desire, that public benefit may be the result.

Manchester,
March 1, 1833.

A TREATISE

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&c. &c.

INTRODUCTORY REMARKS.

THE chief object of the following pages, is to submit to public notice the particulars of what I deem a most important improvement in the construction or formation of Railways.

In the accomplishment of this duty I shall endeavour to be as concise as possible, seeking not fame, on such an occasion, by the extent or brilliancy of language, but by the innate and material value of my subject. How far I am justified in appreciating that value highly, time and experience will testify. At the present moment, after the most mature reflec-

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tion,—after regarding the nature of the improvement to which I allude in all its bearings, and after numerous and impartial experiments, I cannot help feeling a strong presentiment that it will prove one of those important sources of public wealth and advantage, which are decreed at intervals to swell the ever-growing current of civilization.

It is, I believe, universally acknowledged, that in all countries, the rise of prosperity mainly depends upon the convenience of conveyance from place to place. Let those who dispute this doctrine, direct their attention to the resources of any nation with whose condition they are acquainted; let them refer to those historical records which treat of ages gone, and they will find my assertion indisputably verified.

Science, Religion, Morality, Industry, may advance among any particular body, or in any particular district, and according to their joint progress, the comfort and prosperity of that body or district will be promoted; but as the advantages of local situation vary, and as the surplus produce of labour above consumption increases, the necessity of intercourse between man and man proportionately increases; and upon the convenience of that intercourse, whether between nation and nation, district and district, or town and town, in a chief measure depend the value of produce, the general increase of wealth, and, consequently, the advancement of happiness and civilization.

If such be true, no nation can promote its real interests more effectually, than by encouraging in every possible way the establishment of good roads, and rapid and convenient modes of travelling; for according to such convenience will be the equality in price, and the abundance of the supply of produce; the *real* value of landed and other property, and, as before stated, the increase of wealth and comfort among all orders of society.

Entertaining such opinions, it is not to be wondered at that I have for some time watched with anxiety and delight, the successful establishment of the Liverpool and Manchester Railway, and that I look forward with hope that I may live to see the whole of my country interspersed with the same description of roads, every year witnessing improvements, and every community exerting its combined talent and means to promote them.

Thus feeling, and being passionately attached to mechanical pursuits, it was impossible that I could travel along the road to which I have alluded, without endeavouring to make myself thoroughly acquainted with the nature and operations of locomotive power, and drawing my own conclusions as to the perfections or imperfections which attended the present modes of conveyance by such power.

These considerations naturally led to the wish of endeavouring to overcome any difficulty which I believed to exist; and the result of my reasonings upon these subjects, will, I hope, be clearly laid down in the succeeding pages.

ON THE

ADVANTAGES OF RAILWAY CONVEYANCE OVER ANY OTHER MODE, &c.

THE leading advantage which the public can expect to derive by this excellent mode of conveyance, is that of SPEED, either as it regards passengers, cattle, or merchandise.

The limit to speed which has hitherto existed on common roads, is attributable to two causes,—inequality of surface, and circumscribed power. From these two causes, many acknowledged inconveniences, though until now comparatively unfelt, have originated.

About the year 1795, it was a twelve hours' journey from Liverpool to Manchester; a man, therefore, having business to transact in either town, was compelled to sacrifice twenty-four hours of valuable time in travelling.

In the year 1830, the journey from Liverpool to Manchester was, on the average, about four hours; the sacrifice of time was consequently reduced at every journey 1-3rd.

The time it occupied to convey merchandise at these respective periods from one town to the other, was proportionably inconvenient; inasmuch as, before the establishment of canals, the expense and delay by land-carriage was severely felt; and the advantage derived from their establishment was, considering the rates of freight, and the convenience of conveying large quantities of merchandise, fully equal to any advantage derived by passengers from the increased speed of coach-conveyance.

The improvements which have taken place in the speed of conveying goods and passengers by Railways, as at present established upon one line of road, have reduced, since 1830, the loss of time occupied in travelling 5-8ths, and in the conveyance of merchandise 21-24ths; and carrying the same principle into general adoption, how enormous would be the national advantage!

Passengers, merchandise, cattle, &c. can now be conveyed with perfect ease from Liverpool to Manchester, or the contrary way, in one hour and a half, a distance of thirty-one miles.

A person may leave Liverpool at 7 o'clock in the morning, he may devote nine hours to business during the day at Manchester, and he may return to his own house by 7 o'clock the same evening. By similar means, the bale of cotton which leaves Liverpool in the morning, may be in progress of rapid manufacture before the close of evening; and thus the tide of wealth rolls on, swelled by every improvement in science, and essentially promotive of public good.

Momentous, however, as are the benefits which we derive from this speed of conveyance, as an immense assistant to national industry, it is attended with other advantages of great, if not equal importance: it is by such means that we equalize the price of provisions, and of all productions, rendering the produce of one town or district subservient to the wants of others, reducing the expense of travelling, and, as *all wealth* must continually be invested in land or building, thus increasing the real and absolute value of all soil*.

* I trust I may be pardoned for introducing, in the form of a Note, a sentiment, bearing upon my present subject, which I expressed in my "Letter to the Lords and Com-"mons, on the Commercial and Agricultural Condition of "Great Britain," published in 1830: "All the accumulated "wealth of the world must gradually be invested in land, "and every increase of population, cultivation, building, "and civilization, must necessarily enhance the *bonâ-fide* "value of the soil of all countries; as long, therefore, as "any country can maintain her rights and independence, "and is governed by wise and equitable laws, so long "will her land be the best and only security for wealth; "for wealth, like expanded steam, which by ingenuity "is rendered the most powerful engine of production, has "its origin in the self-productive power of land, until, "expanded by labour and ingenuity into immeasurable "space, it falls again condensed upon its native earth, "which is its source, its strength, and its reality."

If this be true, how blind are men to their own interests, who oppose any species of improvement!

Who then can dispute the advantages derivable from every improvement in conveyance, and from the rapid intercourse between place and place, and between man and man?

To deny that these advantages can best be attained by the adoption of Railways, appears to me irrational: the smoothness of surface opens every facility to the acquirement of convenient speed, by the reduction of friction; and the power of steam possesses the most undoubted advantage over every other known assistant power in promoting that speed; and in proportion to the extent of such power employed, in a great measure *ought* to depend the amount of load conveyed.

These advantages have been distinctly and indisputably proved by the result of two years' experience on the Liverpool and Manchester Railway; for, despite of the original expense of this wonderful undertaking, the heavy cost of the numerous locomotive engines at work upon it, the great expense of the servants and labourers employed upon it, and the many necessary attendant outlays, it has, while conferring the greatest possible benefit upon the public, by conveying both passengers and merchandise so rapidly, and at such reduced charges, hitherto produced, after the payment of interest, an ample equivalent to the enlightened, patriotic, and high-spirited individuals who have conferred this blessing on their country.

I cannot leave this subject, without offering my tribute of respect and praise to Mr. G. Stephenson, who has so very ably conducted this undertaking; he has proved himself, in perseverance and in talent, well deserving of the regard of his country and mankind. His fame can never be tarnished by the improvements which others may suggest; and to his candour I have little hesitation in referring the following opinions:

On the Objections which naturally occur to the immediate general Establishment of Railways, and Imperfections in the present Mode of Railway Conveyance.

Among the most important objections to the general establishment of Railways at the present period, and to their successful adoption throughout Great Britain, are the following:

1. The great inconvenience which persons must, for a while, sustain by their accustomed modes of conveyance being withdrawn from the roads to which their property is contiguous.—The great expense of excavations and levelling, of building bridges, tunnels, &c. and of purchasing property;—and, The opposition which landed proprietors are, in general, disposed to offer to new roads being

cut through their estates, and canal proprietors to a competition so injurious to their interests.

2. The difficulty of ascending inclined planes.

3. The great weight of locomotive engines, which are consequently so destructive of the rails or trams, and their rapid wear and tear.—The limit which exists to the full employment of great steam power, and, consequently, of conveying in one train so great a number of passengers, or weight of merchandise, as could otherwise be carried.

1.—*The great Inconvenience which Persons must, for a while, sustain, by their accustomed Modes of Conveyance being withdrawn from the Roads to which their Property is contiguous, &c. &c. &c.*

So great have been the improvements in the common turnpike-roads throughout Great Britain within the last fifty years, that, taking them in general, it would be almost impossible to select more convenient lines of road from town to town. It is true, that many alterations are essential for the saving of distance, and to avoid mountainous ground; but we find these desirable alterations continually going on, as the various Trusts can command, or, otherwise, the requisite funds.

Now, when we seriously consider the enormous expenditure which has been incurred to establish these roads,—the numerous buildings and farms which are contiguous to them,—the well-constructed bridges by which we cross every stream and river throughout the empire,—how conveniently they stretch through every town and village of the slightest note,—and how much the value of property in those towns and villages depends upon direct and convenient communication with other districts,—we cannot help confessing, that the establishment of new lines of roads, in different directions, must, for a time, have the effect of depreciating the value of immense property, and producing excessive inconvenience to many individuals, and to many estates.

It is true, that the present roads may still exist, but where will be the stage-coaches and stage-waggons?—where the necessity of expending the same money in repairs?—what will become of the numerous taverns already erected for the convenience of travellers?—and how serious the inconvenience to the inhabitants of country residences, and to farmers, by these alterations!

Again, when we consider the great outlay that has been made in the establishment of canals for the conveyance of merchandise, we are equally struck with the loss of property which the canal proprietors must suffer, by the construction of new lines of road for Railway conveyance; and the recent fate of the London and Birmingham Railway Bill, in the House of Lords, is rather staggering evidence of the disinclination of some landed proprietors to disfigure (in their opinion) even a small portion of their property for the public good.

I do not thus argue, with a view of advocating the undue protection of private, at the expense of public interests, but to prove how natural and how extensive is the opposition which for many years may be reasonably expected to the general adoption of new lines of road, however great the public convenience.

The preceding may therefore be fairly stated as strong objections to the *immediate general* establishment of Railways; and to these may be added, with truth, the enormous first cost of purchasing property, and of levelling Railroads, throughout a country like England; an opinion of which may be formed, by considering that the Liverpool and Manchester line did not cost less than one million sterling; and if thirty-one miles cost one million, how great would be the expense, upon the most economical plan, of interspersing Great Britain with such lines of road!

To these objections, therefore, my attention has been particularly directed. How desirable would it be to remove such objections,—to reconcile as much as possible the landholder and the canal proprietor,—to free the public who now reside in particular districts, from that inconvenience and loss which they must sustain, from the depreciation of their property, by the removal of their accustomed means of conveyance,—to give to the towns and villages through which a turnpike-road now passes, the same facilities which they at present possess,—and how desirable to save, if possible, the immense outlay which must be made for the purchase of land for new lines of road!

It is quite obvious, that if Great Britain could command sufficient funds,—if the majority of landed and canal proprietors were favorable to such a measure,—and if Parliament would sanction the public wish, the construction of new lines of road would not only give employment to thousands who, *under our present unwise and restricted commercial laws, require it,* but be of undoubted public advantage. But I am inclined to think, if there prove to be no *practical* objections, that more general satisfaction would be given, much valuable time would be saved, and very great, though not equal advantage would result, by the establishment of Railways upon, or contiguous to, the present turnpike-roads, or by the conversion of canals to Railways. These are important considerations, and well worthy of attention. The objections which arise are, nevertheless, numerous, especially in reference to turnpike-roads; I think them, however, by no means insuperable, nor do I conceive the difficulty of ascending the *locks*, nor the indirect course of canals, any serious obstacles to their conversion to Railways.

These are matters, however, for public judgment. If men would consent to make private sacrifices for public good, *entirely new lines of road are best;* but if not, we had far better take all the immediate advantage possible of every improvement in science, than allow those improvements to slumber, even for a single year.

Men are too apt to form their opinions of general welfare by a comparison with self-interest. Nothing can be so egregiously erroneous,—nothing more fatal to the prosperity of a state; and although I ought, perhaps, to apologize for mingling a political sentiment with scientific matter, yet I cannot withhold an opinion, which History and modern example fully establish, that Governments, like individuals, seldom commit an error in judgment where the immediate advantage of the few is sacrificed to the prospective advantage of the many.

2.—*The Difficulty of Ascending Inclined Planes by Locomotive Power.*

This difficulty is amply proved by the Railways already established, and may be witnessed either upon the Liverpool and Manchester, or upon the Bolton lines. The cause is obvious. Whenever the gravity of a body, or its natural tendency to descend, is greater than the resistance produced by the adhesion, or friction, of the wheels upon the surface of the plane, an advance of the carriage is impossible; consequently, upon all inclined planes, the power as well as the speed of ascent is altogether governed by the amount of friction; which friction may be termed the fulcrum upon which the power of steam can be more or less effective; from this has arisen the necessity, which has hitherto existed, of levelling land for Railroads, so as to avoid inclined planes. It is true, that either stationary engines, or locomotive engines with cog-wheels, would enable carriages to be drawn up inclined planes, but such modes would be attended with serious, if not insuperable inconveniences; and hence the great difficulty, hitherto, of conveying merchandise or passengers by steam upon common turnpike-roads*, even if rails, or trams, were laid down thereon: to this second objection, therefore, my attention was particularly directed.

* I am aware that steam-carriages have been constructed to ascend hills with heavy loads on common turnpike-roads; but when I consider the *amount of friction* necessary to be overcome, I cannot believe that steam power can ever be rendered *advantageously* effective on such roads.

3.—*The great Weight of Locomotive Engines, which are consequently so destructive to the Rails, or Tram-plates, &c. &c.*

I had not long witnessed the experiments tried by Mr. Stephenson and others upon the Liverpool and Manchester line of road, before I drew the conclusion, that the load conveyed, and the speed of conveyance, did not so much depend upon the *extra power of steam*, as upon the *extra weight of the engine;* in other words, that in proportion to the weight of the apparatus, is the amount of pressure upon a common Railroad, and, consequently, the amount of power absolutely at work. Indeed, I soon formed the opinion, that if 30-horse power of steam were applied on a common Railway, with an extremely light apparatus, it would not convey so great a weight of goods, or so rapidly, as 10-horse power of steam with a heavy apparatus; and an observation is scarcely necessary to prove the disadvantages attendant upon heavy engines, where light ones can be rendered effective.

Referring to the following figure, let A B, be a common Tramroad, upon a level,—C,

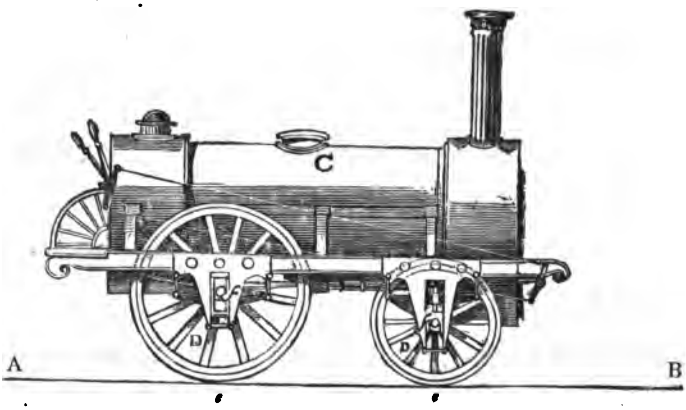

Fig. 1.

the engine,—D D, the wheels,—*e e*, the points of friction upon the plane,—*f f*, the points of friction upon the axles.

Now the only power of steam which the engine C, can effectually employ, is in proportion to the amount of friction at the points *e e* and *f f*; and the amount of this friction is in proportion to the weight of the engine C; governed of course by the diameter of the wheels and axles.

Now, supposing the amount of this friction be just sufficient to render 10-horse power of steam effective in dragging 50 tons;—and supposing 10-horse power of steam just sufficient to move the wheels, D D, along the plane, without slipping, with the load attached;—if we were to add 30-horse power of steam in addition, without increasing the weight of the engine, the machine would not be more effective; for if we added 20 tons to the weight dragged, the friction or adhesion at *e e* would not be increased by any power of steam, and, consequently, the wheels would simply turn upon their axis, and the whole train would remain stationary:—that is, the comparative quantity of goods or passengers conveyed upon a Railroad, as at present constructed, by different engines, does not depend upon the extent of steam power we have at disposal, but upon the *weight* of the engines, which altogether governs the amount of effective power.

This compulsion to employ such extremely heavy engines, is, it cannot be disputed, a serious subject of scientific consideration. That such engines have been found necessary by Mr. Stephenson, is obvious; for without them, he could not convey the loads of merchandise and the number of passengers in one train, which he now does. The result is obvious, that the immense pressure produced upon the rails, naturally leads to their more rapid wear; and in many parts of the Liverpool and Manchester line, this effect is even now visible. Nor is the injury confined to the rails; for the wear of the engine-wheels is proportionately great; and, by comparing them with the wheels of the lighter vehicles, the truth of these objections will be evident. I therefore am strongly impressed with the belief, that one of the greatest desiderata in

Railway improvements, *is that of reducing*, *as much as possible, the weight of the locomotive engines.*

From the preceeding observations it will be obvious, that as the effect of locomotive power, as also proved by experience, depends altogether upon the amount of friction produced by the pressure of the periphery of the wheels upon the rails, if a given power of steam be employed, and if such power be just sufficient to turn the wheels without slipping, with a maximum load attached, any increase in that power is altogether useless; indeed, upon the Railways already established, the full power of steam is seldom or ever exercised; and for the evident reason, that the friction, or fulcrum, is not sufficient to allow of its full activity; for, as before observed, whenever the load to be conveyed is just such as to permit of the steam power moving the wheels of the engine along the plane without slipping, no increase whatever of that power, whether 50, 60, or 100-horse, could enable the engine to draw the load.

From this reasoning I was led to form the opinion, that locomotive steam power never could be brought to any thing like effectual operation upon a Railway, until greater activity could be given to its exercise, and until we depended more than we now do upon the *extent* of that power, for the amount of weight we should be capable of conveying.

The speed of a steam-vessel depends principally upon the *extent of power* employed to overcome friction;—the quantity of machinery moved in any manufactory, or the quantity of ore or water drawn from any mine, depend upon the same *extent of power;*—but upon Railways, as at present constructed, the speed of the train, and the weight conveyed, depend more upon the *extent of the weight of the engine*, than upon the *extent of steam power.*

The weight, too, of a locomotive engine, as now used, is one great cause of its heavy first cost. The body of the carriage being so ponderous, it becomes essential that all the wheels, the axles, and every other part of the machinery, should be proportionately so; and this great weight leads, as before observed, to their rapid wear; so much so, that few of these engines last beyond 12 to 18 months; they are frequently out of repair, and the original cost of each is from £600 to £800. Now, when we consider the length of time which the engine in a vessel will endure*, and how many years a stationary engine will work, we are at once compelled to infer, that there is some great error in the present mode of adapting locomotive power to Railways. The whole riddle is, that *fulcrum*, or *resistance*, *is wanted;* and until this can be given to the fuller activity of steam, neither light nor cheap

* It is quite true, as Dr. Lardner observes, that the immense distance which locomotive engines travel, ought to be taken into consideration when we speak of their short duration; but this, in my opinion, is not a sufficient justification of the evil I speak of.

engines can be employed: it is, in a word, the want of this resistance that, upon Railways, as at present constructed, prevents the ascent of inclined planes, and leads to the more rapid wear and tear of the engines, which are constantly overstrained, and, in my opinion, far too ponderous, and, however highly we may already appreciate them, are by no means perfect in their operations.

How to remove these evils, at least in part, I shall endeavour to explain in a following Section. Before closing this, however, I am anxious to point out another objection which occurs to me in the present adaptation of carriages to Railway conveyance; I allude to the unpleasant jolting which, at every start of the carriage, is felt by the passengers.

Although this is a very minor evil, it is, nevertheless, important that it should be remedied. The plan I propose is, to attach the carriages together by strong rods, moving on ball and socket-joints.—(See *fig*. 2).

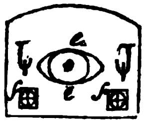

Fig. 2.

A B, is a rod by which two carriages are to be joined together, to the end of which are the balls, *c c*;—*e e*, are the sockets which open to admit the balls, and which are firmly attached to each carriage by the screws, *f f*, and are so made as to admit of the rod, A B, being moved with ease in any direction.

By this means, it is evident that each carriage will accommodate itself to the motion of the others, and that the chains now employed being thus dispensed with, the jolt which is now experienced at the starting of the carriages, and which is owing to their being drawn together when stopping, by their momentum, will be no longer experienced.

ON THE NATURE OF THE IMPROVEMENT TO WHICH THESE PAGES REFER; THE PRINCIPLES ON WHICH IT IS FOUNDED, AND THE ADVANTAGES LIKELY TO ACCRUE THEREFROM.

THE improvement in the formation or construction of Railways, to which these pages principally refer, is the substitution of a *curved*, or *undulating*, or, what I denominate, a *serpentine Railway*, for the horizontal Railway now in use.

The improvement occurred to me on the 7th June, 1832. The impressions upon my mind, before the trial of any experiments, were, that by an undulating Railway, a greater resistance would be opposed to the power of steam, or any other locomotive power, than upon a level Railway; that much would be gained by the power of gravity, multiplied by active power, down a descent; and that, consequently, a locomotive engine of any given power, would travel at a greater speed, or drag a greater weight, than upon a horizontal Railway.

I was also of opinion, that the increased resistance, or fulcrum, offered by the descending part of each curve, and the advantage gained by the power of gravity, multiplied by active power, would be sufficiently great to render locomotive engines more effective than they have at present proved to be, up inclined planes. How far these opinions are warranted by experiments, the following remarks will shew; before I proceed, however, to describe them, I consider it necessary to make some observations on the subjects of *friction* and *gravity*, which are essential to a clear understanding of my discussion.

If one plane surface, being a dead weight, be dragged over another plane surface, the amount of friction will be in exact proportion to the weight of the body dragged; but if such body be placed upon four wheels, and rolled along a plane surface, the attrition produced by the dead weight is principally removed, and the only friction is that produced by the rolling of the peripheries of the wheels along the surface of the plane, and the friction, or attrition, produced by the revolution of the axles; the total amount of this friction being altogether determined by the weight of the vehicle, the smoothness of the plane upon which the body moves, and the diameters of the wheels and axles.

It is difficult to establish any decided data as to the proper comparative amount of rolling friction and axle friction, as they vary in almost every carriage or engine; but, taking the experiments of Mr. Nicholas Wood as a guide, they may, jointly, be stated to be, in Mr. Stephenson's earlier locomotive engines, about the 240th of the entire weight, and their proportions as 6 to 19;—the rolling friction being 6, the friction upon the axle being 19.

Adopting also the formula of Mr. Wood,

the power required to move a locomotive carriage on a Railway, will be as follows:

Let W, be the weight of the carriage.
W′, that part resting upon the axles.
f, = to the rolling friction on the plane.
g, = to the friction upon the axles, in part of the weight, $W' = f' \frac{d}{D}$.
D, = diameter of the wheels.
d, = diameter of the axles.
P, the power required to move the vehicle.

Then,
$$P = \frac{W}{f} + \frac{W'}{f' + \frac{d}{D}}.$$

The power, P, would be equally effective, and in the same proportion, were a stationary engine employed in moving a whole train of carriages; but when locomotive power is employed in one vehicle to drag numerous vehicles, it will be evident, that the extent of such power will depend upon the weight of the vehicle on which it immediately operates, or, what is tantamount, upon the absolute amount of friction between the periphery of the wheels of such particular engine, and the plane on which it travels.

Remarking upon the preceeding formula, Mr. Wood observes, "We have no decided "experiments to prove the value of *f*, with "different-sized wheels; but as large wheels "more easily surmount obstacles than wheels "of small diameter, we may *suppose* the "former will always be preferable."

Now, in my opinion, there is no mechanical principle more established, than that the greater the diameter of a cylinder of a given weight, rolling on a plane, the less is the amount of friction. For instance, if a carriage weighing 1 ton, move on 4 wheels of 4 feet diameter each, whose axles are of given dimensions, and the same carriage, with the same axles*, move on wheels of 2 feet diameter each, the amount of pressure being the same, the rolling friction of the 2-feet wheels would exceed the rolling friction of the 4-feet, in the proportion of 4 to 2.

* Of course, axles of the *same* dimensions would not, in this case, be necessary: it is for the purpose of clearer elucidation that I have considered them, in this instance, alike.

Again, I look upon the amount of friction, or attrition, produced by the moving of a wheel upon its axis, or of an axle within a stationary cylinder, to be clearly demonstrable, the diameter of the axle and the diameter of the cylinder, as well as the amount of pressure, being ascertained. In this instance, the amount of friction, or attrition, does not altogether depend upon the amount of pressure, but on the leverage gained by the less or greater diameter of the wheel.—Thus:

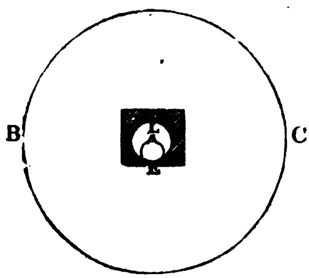

Fig. 3.

A, is the axle of the wheel, B C, revolving in the hollow cylinder, D E, the point of friction, or attrition, being at E, with a leverage, E L.

Now, let P be the power employed to move the wheels round, and it is evident, that the wheel, when revolving, acts with a leverage, B A, in overcoming the friction, F.—Thus:

$$F : P :: BA : EL$$

$$F = P \frac{BA}{EL};$$

shewing, that the point of attrition at E, is equal to the power applied, P, multiplied by the radius of the wheel, B A, and divided by the radius of cylinder, D E, in which the axle revolves.

Having thus, I conceive, sufficiently explained, for our present purpose, the nature of rolling friction, and of the attrition produced by the pressure of the axles, I have only on this point to add, that it is the former which alone and altogether determines the amount of resistance, or extent of fulcrum, upon which the power of steam in locomotive carriages can be rendered effective. Hence it will be evident, that if a load be attached to a locomotive engine, sufficiently great to counteract or overcome the amount of the adhesion, or friction, produced by the gravity of such engine, the engine itself cannot progress, but the wheels will simply revolve, without progressing; consequently, *the load which a locomotive engine will convey upon a horizontal Railway, as at present constructed, is always in proportion to the gravity, or weight, of the engine, and the friction upon the rails produced thereby.*

Having said thus much on the subject of friction, I am anxious to make a few remarks on the laws of gravity, which I consider it requisite to define, in order to elucidate, as clearly as I can, the merits and nature of my improvement.

If a carriage descend freely down an inclined plane, and pass over a certain space in the first minute of its fall, it will pass over 4 times that space in the 2 first minutes, and 9 times that space in the 3 first minutes; the force of descent down the incline, being to the force with which it would descend perpendicularly, as the height of the plane to its length; or to ascertain the space which it would pass over down a regular incline, in any number of minutes, we have only to multiply the space through which it descends in one minute, by the square of the number of minutes in the time of the fall. Thus the velocities with which bodies descend, and the spaces which they pass over, whether down inclines, or perpendicularly, increase in the following ratio:

1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21;

shewing, that if a carriage descend five yards in the first second of time, in the next second second it will fall *three* times five, or 15 yards; the whole space passed over, as above remarked, being 20 yards; and so on in exact proportion. This motion of descending bodies, is termed their *accelerating motion;* and if any power be employed to assist this force of gravity, the descent is more or less rapid, in proportion to the extent of that power. For instance, let v represent the velocity which a carriage dragged down an inclined plane would acquire in one second of time, and let N be the number of seconds taken in descending from the top to the bottom of the incline, and let V be the total velocity gained; then we have,

$$V = v N.$$

Again, let s be the *space* the carriage would pass over in the first second, and $s N^2$ the space it would pass over in the number of seconds expressed by N, and let S represent such space; then we have,

$$S = s N^2;$$

or, to be more explanatory, the space over which a carriage will travel down an inclined plane in any number of seconds, may always be ascertained, by subtracting the space passed over in one second, from the space passed over in the first two seconds. Thus, if s represents the former, $4s$ will represent the latter, and the difference is $3s$, or,

$$4s - s = 3s;$$

and the space passed over in the third second of time, will be ascertained in like manner, viz. by subtracting the space passed over in the first two seconds, from the space passed over in the first three seconds, which latter space is nine seconds; thus,

$$9s - 4s = 5s.$$

To those of my Readers who may be unacquainted with mechanics, the following Table may be useful, in reference to the particular object of these pages; it represents the spaces over which bodies pass, the *velocities* which they acquire, and the *times* in which they descend, either perpendicularly, or down inclined planes; the comparative difference between the time of descent down a perpendicular, and inclined plane, being in proportion to the angle of inclination, and the friction; and the total time of descent altogether depending upon the time of descent, and space passed over, in the first second.

No. of Seconds taken in Descending.	Velocities acquired at each Second.	Whole Spaces passed over in each Second.	Separate Spaces passed over in each Second.
1	2	1	1
2	4	4	3
3	6	9	5
4	8	16	7
5	10	25	9
6	12	36	11
7	14	49	13
8	16	64	15
9	18	81	17
10	20	100	19

and so on.

My remarks on gravity have hitherto been confined to the operation of bodies, in their descent down inclined planes, &c.; but this operation widely differs in their *ascent* of inclined planes, and it is to this difference I am anxious to call particular attention.

If a power be employed to drag a body up an inclined plane, the velocities are equal, and the spaces passed over in each second are equal; the ascent, therefore, will be,

Number of Seconds.	Separate Spaces passed over.	Whole Spaces passed over.
1	1	1
2	1	2
3	1	3
4	1	4

namely, it will pass over the same space in the second second as it did in the first second, and the same in the third as in the second, and so on. This, however, would not be the case if a body were driven by a single blow up an inclined plane; in such case, the motion would be gradually retarded, in the proportions,

10, 9, 8, 7, 6, 5, 4, 3, 2, 1,

until the power were expended; when it would of course descend, or run back, by its own gravity.

It is true, that the counteracting power of gravity upon all bodies dragged up inclined planes diminishes the higher the body ascends; but this diminution is so extremely minute, that it may be considered altogether unimportant, as, in practice, it is; for if the rise of the plane be one yard, the difference in the counteraction of gravity at the top and bottom of the plane, is merely as one yard to the distance between the surface and centre of the earth.

Having thus endeavoured to explain the laws which govern the motion of bodies in the descent or rise of inclined planes, and allowing the principle I previously laid down to be correct, viz. *that the load which a locomotive engine will convey upon a horizontal Railway, as at present constructed, to be always in proportion to the gravity, or weight, of the engine, and the friction upon the rails produced thereby,*—I will proceed to an explanation of the principles upon which I hope to establish the merit of my improvement in Railways.

Supposing the three wheels, or carriages, A B C (*figs.* 4, 5, 6), to be all of exactly the same weight and diameters, and the diameters of their axles the same, and that a given power be required to move the carriage A along the line D E, viz. from D to E, by

Fig. 4.

a *stationary* engine. Now, if the same power be applied to move the carriage B up the inclined plane F G, it will be ineffectual. It

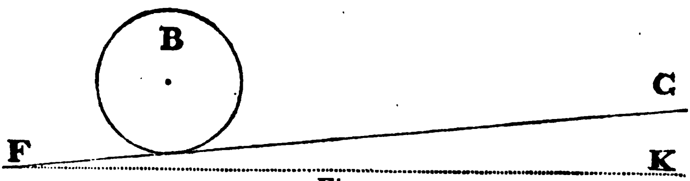

Fig. 5.

must, therefore, be increased in proportion to the angle G F K; but, supposing the angle L I H equal to the angle G F K, the

Fig. 6.

power required to move the carriage C down the incline H I, at the same speed, would be much less in proportion to the power required to move the carriage A on the level, than the excess of power required to move the carriage B up the incline F G.

This difference will be the gravity of the descending carriage, C, which gravity is an accelerating or multiplying motive power*, in addition to the assistant power supposed to be employed; whereas, the ascent up the inclined plane G F, is equal, and the resistance of the carriage B, by gravity and friction, is a regular, and not a multiplying resistance.

We will now suppose that the vehicles A B C are locomotive engines, and that a given power is employed, sufficient exactly to move A over the surface D E, dragging any

* In using the words "*accelerating, or multiplying* "*motive power*," it may be said that I ought, more properly, to have appropriated the words, "this difference "will be the *accelerated velocity, produced by the con*"*stant power of gravity*;" but as accelerated velocity produces increased momentum, or as accelerated velocity produces increased centrifugal force, I know not how I can better describe the action of gravity on descending bodies, than by terming it "an accelerating, or multi-"plying motive power."

maximum weight after it, (meaning, by maximum weight, such a weight as will not be too great to counteract the friction between the engine and the plane, which friction, as a fulcrum, renders steam power effective). Now, the power required to move the engine B up the incline F G, will be as before, according to the angle G F K, but if we attach the same weight to B as to A, no increase of steam power could drag such weight up the incline; inasmuch as when the weight was attached to A, it was exactly that which the friction of the carriage A upon the plane, as a fulcrum, could enable the engine to surmount; but on the incline F G, the resistance, or friction, of the engine B upon the surface, is reduced in proportion to the angle G F K, and, therefore, exclusive of the difference in power requisite to move the two engines and their loads by fixed engines, is the difference in the fulcrums, or resistance, by which locomotive power can be rendered effective.

The comparative quantity of goods, therefore, which can be drawn up an inclined plane, and upon a level, by any given locomotive power, differs very materially from the comparative quantity of goods which can be drawn up an inclined plane, and upon a level, by a given power from a fixed engine.

Let us now look at the descent, and we shall find these properties widely different. If the carriage C move down H I, assisted by the power of a stationary engine, that power will be, as before stated, less in proportion to the power employed to move A, than the excess of power employed to move B, owing to the accelerating power of gravity; but, supposing C to be a locomotive engine, with the same weight attached to it as was attached to A, and employing the *same* power as A, that power would not only be more effective than it was along D E, in proportion to the angle H I L, but, in addition to the resistance offered to steam power, by the friction of the engine-wheels upon the plane, and which friction, like that on F G, will be in proportion to the angle of the incline, is the resistance of the accelerating power of gravity, or accumulating momentum, not only of the engine, but the load behind it, which becomes an additional and most important fulcrum for the effective power of steam.

The preceding remarks will shew the basis upon which the serpentine or undulating Railway, as a mechanical question, depends; it will also prove how desirable it is that upon all roads the surface should be undulating, instead of the perfect level, provided the descents be not too great, to render the force of gravity dangerous, when multiplied by other constantly effective power.

In further elucidation—Supposing the car-

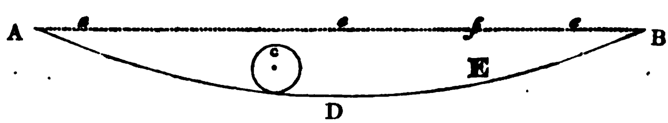

Fig. 7.

riage C to be travelling from A to B, along the curve A D B, impelled by any *constant* *and equal power*—in its descent to D, the speed will be increased by the accelerating power of gravity, multiplied (if I may so express myself) by the accumulating effect of constant and equal power; whereas, in its ascent from D to B, it has, notwithstanding the counteraction, by gravity, of the momentum gained (though, *in this case*, uniformly retarding), the advantage of such constant and equal power to support its motion.

Now, supposing that, without the employment of power, a carriage be placed at the point A, it would not *move* upon the level, *e e e*, but it would run down A D, and ascend the line D B to a certain distance, which distance depends upon the momentum gained by the accelerating force of gravity, and which momentum, as in all other cases, is *in proportion to the velocity of the body, multiplied by its weight*. Now, supposing the carriage to have risen up the incline D B, as far as E, we have here a space travelled over equal to

A *f*; and it is to the result of this accumulating momentum produced by gravity, multiplied by the accumulating effect of power, that I principally look for the advantage derivable from an undulating line of road.

If locomotive power be employed to work a carriage along the dotted line *e e e*, to which engine is attached another vehicle, just heavy enough to admit of progression, it would accomplish the task in a given time. Now, if these carriages were placed at the point D, it is evident that they could not ascend, for the reasons stated in page 47; but if the same carriages be placed at the point A, the descent to D will not only be much more rapid than any part of the advance along the line *e e e*, but the momentum produced by the accelerating power of gravity, multiplied by the accumulating effect of power, will have increased to such a degree, that it will *counteract the difficulty of ascent from* D *to* B, and the vehicles would arrive at B in *very* *much less time* than they would have occupied in travelling along *e e e*.

By way of proving the truth of these observations, I had a curve made of the following proportions: From A to B was 4 feet; depth of the curve 2 inches. *a*, is a roller so constructed as to move easily along the curve, and to revolve upon its axis, to each end of

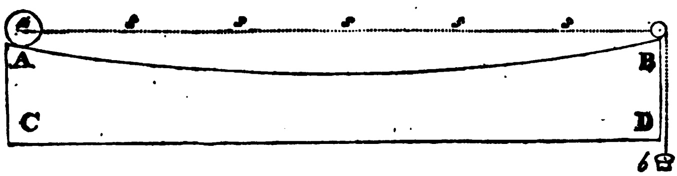

Fig. 8.

which was attached the string, *s s s s s*, which, passing over a pulley at B, had a small paper box, *b*, suspended from it.

By reversing the solid piece of wood, A B C D, the same roller, string, and suspended box, were made to operate on the horizontal surface, C D.

The following experiments were made with different weights, just sufficient to move the roller, *a*, along the surface, C D, when perfectly horizontal, and at different inclinations:

Inclinations.	Time in passing over the Horizontal Plane.	Time in passing over the Curve.
	Seconds.	Seconds.
On a perfect Level	$2\frac{1}{2}$	$1\frac{1}{2}$
Inches. Inches. Rise of 3 in 48	3	2
4 in 48	5	2
5 in 48	5	2
6 in 48	6	$2\frac{1}{8}$

Thus shewing, that the greater the angle of the incline, the longer was the time required in passing along the plane, C D; whilst on the curve, A B, the same exact weight being employed at each experiment as along C D, the speed scarcely varied, and, upon all occasions, was considerably greater than upon the horizontal plane.

By way of reducing my opinions, however, to certainty, and in order to judge of the effect of locomotive power on an undulating line, by the test of experiment, I ordered a small engine to be manufactured, on clock-work principles, with a strong spring in a barrel, and a fusee sufficiently large to admit of travelling the length of 50 or 60 feet, being also particularly anxious that the power of the spring should be sufficient to overcome the pressure of the engine-wheels on the plane, when kept from progressing. Wishing to try these experiments as privately as possible, during the time which the manufacture of the engine occupied, I was engaged at Douglas, in the Isle of Man, in superintending the making of two Railways, the one curved, the other horizontal.

These were each 32 feet in length (the length of the most spacious room I could find unoccupied); the length of the ascent and descent of each curve, or undulation, was *one foot;* and the height and depth of each curve from the centre, was half an inch, or one inch from the summit of the convex to the base of the concave of the curve.

I had also ordered a small carriage to be made, to be attached to the engine, when necessary, and to run upon four wheels of the same diameter as the wheels of the engine.

On the 23rd July I received the engine and carriage from Liverpool; their weights were as follows:

Weight of engine	9lbs. 6 oz.
Weight of carriage	3lbs. 10 oz.
Diameter of wheels	3 inches.
Width of the periphery of the wheels	3-8ths of an inch.

On trying the strength of the spring, I was sorry to observe that it was not sufficient, when I placed the carriage on a smooth surface, and prevented its progression, to turn the wheels; that is, it had not power, as I wished it to have, to overcome the adhesion, or friction, between the wheels of the carriage and the surface of the plane.

I, however, resolved to try a series of experiments with it, and afterwards to return it to Liverpool, to have a stronger spring attached to it.

Accordingly, I had the Railways placed firmly down, and upon as exact a level as circumstances would permit. The distance between the lines on each Railway was eight inches; the width at the surface of the rails was half an inch; the distance between the wheels of the engine governed, of course, the width between the lines; and care was taken to give the carriages sufficient play, to prevent them being bound by friction against the sides of the rails.

Having ascertained that both Railways were level, the spring was wound up, by drawing the engine backwards from the end of the line to the commencement. It was started without any weight attached, and the following was the result:

On the Curved Railway,	On the Horizontal Railway,
6 seconds.	7 seconds.

I then placed 7 lbs. weight upon the engine itself, which had a platform for such purpose; the result was,

On the Curve,	On the Horizontal Railway,
8 seconds.	9 seconds.

I then attached the small carriage to the engine, and, without load, I found the speed of travelling along either line, was in the same proportion as before.

I then tried various weights in the carriage, and invariably found a decided advantage in the curved Railway. This advantage was, however, more evident in the following experiments:

With 17 lbs weight in the carriage.

From North to South,

Curved Railway,	Horizontal Railway,
15½ seconds.	20½ seconds.

From South to North,

Curved Railway,	Horizontal Railway,
17 seconds.	22½ seconds.

Now, omitting the half-seconds, and taking the averages, the difference of space which the engine would have travelled over on the curve, in the time required to travel 32 feet on the horizontal plane, is as follows:

16 : 32 :: 21 : 42 feet;

shewing a difference of nearly 1-3rd in the speed.

Thinking it probable that, by the variation in the time occupied in traversing the lines from different sides of the room, that they might not be perfectly level, I had them again examined and adjusted with particular caution; after which, on again trying, with the same weight, viz. 17 lbs. the result was as follows:

From North to South, and South to North,

On the Curve,	On the Level,
16 seconds.	22 seconds.

This last experiment was repeatedly tried, and without any distinct variation; the time was ascertained by a second-hand watch, and carefully noted by Mr. J. L. Gardener, of Manchester, who witnessed the experiments, as well as myself.

Although I perceived that 17 lbs. was as great a weight as the engine could well convey upon the horizontal Railway, I was anxious to try the result of greater, and increased the load to 22 lbs. The result was, *From North to South,*

On the Curve,	On the Horizontal Line,
17 seconds.	30 seconds.

From South to North,

On the Curve,	On the Horizontal,
18 seconds.	28 seconds.

It was here quite obvious, that the curve produced a far more decided advantage; and this advantage was evident at starting; as, on the horizontal road, the engine moved very slowly at first, and traversed 12 or 13 feet before it attained its average speed; whereas, upon the curved line, its motion was apparently regular throughout.

Although these experiments were, in every point of view, so satisfactory, in regard to speed, I was surprized to find that the advantage was not so great as I anticipated in regard to the difference of load the engine was capable of dragging on the two lines. I, however, clearly proved that we could convey a much greater weight upon the curved line than upon the plane; for when the engine would not move at all upon the horizontal road, it would travel without difficulty upon the curve; and it is extraordinary, that in conveying any weight, from 15lbs. upwards, on the latter, the time occupied in doing so, varied in a very trifling degree.

The same comparative results took place up an inclined plane of 1 in 144.

After repeated trials, and the most evident proofs of the success of these experiments, I sent the engine back to Liverpool on the 31st July, with instructions to the maker to increase the strength of the spring as much as possible, under the conviction, that when I had the opportunity of employing greater power, the result would be much more decisive, and the advantage more determinable.

During the delay which necessarily occurred in altering the engine, I ordered another Railway to be laid down, feeling quite convinced that, if my curves were longer than those which I had already tried, the advantage would be proportionate. It also occurred to me, that as the distance between the hind and fore-wheels of the engine was equal to the length of the descent of my curve, it was impossible that I could have gained any very material advantage by gravity, except by means of the carriage attached, containing the load, the hind and fore-wheels of which were only $6\frac{6}{16}$ inches apart.

The Railway above alluded to, was the same length as the two former ones, viz. 32 feet; the ascent of each curve being 5 feet, and the descent 5 feet; and the height and depth from the centre 1 inch, or 2 inches from the summit of the convex to the base ot the concave of the curve.

On the return of the engine from Liverpool, I was gratified by finding a great increase in its power, though still it was not sufficient to move the wheels round when the body of the engine was kept from progressing;

and this could not be remedied without altering the arrangement of the wheels and pinions, and of course reducing the distance over which the engine was calculated to travel. I considered, however, that it was sufficiently powerful to answer every purpose of preliminary experiment, and on the 8th August I proceeded to try my further experiments, of which the following is the result:

	Number of Seconds.		
	Horizontal Plane.	1-foot Curve.	5-feet Curve.
Engine alone, weighing 9 lbs. 4 oz.* and the hind and fore-wheels $6\frac{1}{16}$ inches apart	5	4	$3\frac{1}{2}$
Ditto, and carriage, weighing together 12 lbs. 14 oz.	$5\frac{1}{2}$	$4\frac{1}{2}$	4
Ditto, with 5 lbs. in carriage	$6\frac{3}{4}$	$5\frac{1}{4}$	$4\frac{1}{2}$
Ditto, with 10 — in ditto ..	$8\frac{1}{4}$	$6\frac{1}{2}$	$5\frac{1}{2}$
Ditto, with 15 — in ditto ..	$9\frac{3}{4}$	7	6
Ditto, with 20 — in ditto ..	$13\frac{1}{2}$	$8\frac{3}{4}$	$7\frac{1}{2}$
Ditto, with 25 — in ditto ..	18	11	9
Ditto, with 30 — in ditto	30 could scarcely go.	14	11
Ditto, with 35 — in ditto ..	could not go.	18	12
Ditto, with 40 — in ditto ..	....	....	13
Ditto, with 45 — in ditto ..	....	....	15

* The cause of the engine being lighter than before the alteration, is owing to the iron platform having been removed, with a view of bringing the hind and fore-wheels nearer to each other.

From the preceding statement, two most important results are evident:

1st, That upon a curved line of road, a given weight, moved by a given locomotive power, will travel at much greater speed than upon a horizontal road; and,

2ndly, That a given locomotive power will impel a weight along a curved line of road, which that same power cannot move upon a horizontal road.

The amount of advantage may be in some measure judged of, by reference to the experiments; for instance, it required upon the horizontal plane 13½ seconds to convey 20lbs. over a space of 32 feet; and on the curve, the same weight was conveyed in 7½. Thus:

$$7\frac{1}{2} : 32 :: 13\frac{1}{2} : 57\frac{3}{5} \text{ feet};$$

shewing a decided advantage of full 3-4ths in speed: the comparative advantage increasing with every addition to the weight of load. Moreover, it will be seen, that the same power impelled 40lbs. upon the curve in 13 seconds; proving the capability of carrying upon the curve twice the load that the same engine could impel upon the horizontal plane in the same time.

It will also be seen, as in the previous experiments, that a much greater load could be impelled by a given power upon a curved than upon a horizontal road: inasmuch as the engine had great difficulty in dragging 30 lbs. upon the latter, whereas, upon the former, it carried 45lbs. with facility.

After repeatedly trying the above experiments, in the presence of an individual whose object was to discover, if possible, any defect, and who, on every occasion, when a doubt existed as to time, gave the benefit of that doubt to the horizontal road, I next proceeded to try the effect of the engine up an inclined plane.

The inclination was 9 inches in 32 feet, or 1 foot in $42\frac{2}{3}$. The following is the result:

		Number of Seconds.	
		Horizontal Railway.	5-feet Curved Railway,
Engine alone		6¾	5¼
Engine and carriage, without load		7½	6
Ditto, ditto,	with 1 lb.	8½	6¾
Ditto, ditto,	2 —	9½	7
Ditto, ditto,	3 —	11	7¾
Ditto, ditto,	4 —	12	8¼
Ditto, ditto,	5 —	13¾	8¾
Ditto, ditto,	6 —	16¾	9¼
Ditto, ditto,	7 —	22	10
Ditto, ditto,	8 —	30 would not carry all the way.	12
Ditto, ditto,	9 —	would not go.	14

From this statement, the comparative advantage shewn, is as great as upon the level; for instance, it required 11 seconds to move 3lbs. along the horizontal plane, whereas, upon the curve, 7lbs. were carried in less time, viz. 10 seconds.

After trying these experiments repeatedly, I ordered a fourth Railway to be made, upon a different principle; thinking that, upon double lines of road, it might be found better to have the undulations of long descent and short ascent, from the supposition that, in traversing from A to B, the momentum gained

Fig. 9.

at the points *c c*, would be such, aided by the gravity of the carriages and load attached, as to enable the engine to rise the steep ascents*, *d d*, with ease, when the resistance, or fulcrum, offered down the next descent, would be more continued than upon a regular curve, and would, consequently, give far greater effect to locomotive power; for it will be evident, that, except in the momentary ascents up *d d*, in which ascents the engine is assisted by the still acting gravity of the following carriages, the power will always be acting against the side of a hill, and will, consequently, be more effective.

This Railway was accordingly completed, the length of each descent being 8 feet; the length of each ascent 2 feet; and the whole line being 32 feet. It consisted of 3 descents,

* It is almost unnecessary to remark, that *fig.* 9 is not drawn to a scale; it is solely to render the explanation more distinct, that such deep undulations are represented.

3 ascents, and a platform of 1 foot at each extremity, the tops of which were on an exact level with the summits of each ascent; the depth of descent at the lowest point being 2 inches from the highest rise, as in the Railway whose curves were 5 feet.

It is necessary to remark, that the descents in this Railway, except about a foot from their lowest points, were regular inclined planes, curving off at the bottom, to render the ascents more regular, which ascents were also curved.

The following was the result of experiment:

Number of Seconds.

	On the perfect Level.			Weights.	Inclination of 1 in $42\frac{2}{3}$.		
	Horizontal Plane.	5-feet Curve.	Long & Short Curve.		Horizontal Plane.	5-feet Curve.	Long & Short Curve.
Engine alone	5	3½	4		6½	5¼	5½
Do. and carriage	5½	4	5	lbs.	7½	6	6
Do. with 5lbs. ...	6¾	4½	6	1	8½	6¾	6½
——— 10 — ...	8¼	5½	7	2	9½	7	7
——— 15 — ...	9¾	6	7½	3	11	7¾	7½
——— 20 — ...	13½	7½	8	4	12	8¼	7¾
——— 25 — ...	18	9	8½	5	13¾	8¾	8
——— 30 — ...	33	11	9	6	16¾	9¼	8½
——— 35 — ...	....	12	10	7	22	10	9¼
——— 40 — ...	....	13	11	8	30	12	9¾
——— 45 — ...	....	15	12	9	....	14	10¾
——— 56 — ...	....	......	14	10	....	......	11
——— 58 — ...	....	......	14½	11	....	......	12
——— 59 — ...	....	......	14¾	12	....	......	13
——— 60 —	with great difficulty		16	13	....	......	15½
	....	......	....	13½	....	......	16

Such was the result of my experiments up to this period, shewing, that on the Railway last made, there was considerable advantage in the speed, and the power of conveying heavy weights; and on trying the same engine on the Railway *the reverse way*, the result was found to be the same, although it is a little remarkable, that the speed with which very light weights could be conveyed on this line, when on the perfect level, was, on this trial, not so great as upon the regular curve.

Being, however, satisfied, that both this and the 5-feet curved Railway presented most important and indisputable advantage over the plane, or horizontal road, I induced Mr. Gill, of Manchester (one of the Directors of the contemplated Manchester and Leeds Railway), to visit Douglas, for the purpose of witnessing the experiments.

On his arrival, he very wisely suggested the propriety of fastening all the Railways firmly down upon strong 3-inch planks, to obviate the evident vibration which the Railways sustained, when heavy loads were passing over them: this was accordingly done. Previously, however, he was anxious to witness a few experiments upon an incline which I had prepared, which was about 1 in 94, and these were principally confined to the horizontal Railway, and to the 5-feet curve. The result was as follows:

			Number of Seconds.	
			Horizontal Plane.	Curve.
Engine and carriage			7	5¼
Ditto,	ditto,	with 1 lb.	7¼	6
Ditto,	ditto,	2 —	8	6
Ditto,	ditto,	3 —	8½	6¼
Ditto,	ditto,	4 —	9	6¼
Ditto,	ditto,	5 —	9½	6½
Ditto,	ditto,	6 —	10½	6¾
Ditto,	ditto,	7 —	11	7
Ditto,	ditto,	8 —	12½	7¼
Ditto,	ditto,	9 —	13	7¾
Ditto,	ditto,	10 —	14	8
Ditto,	ditto,	11 —	15	8¼
Ditto,	ditto,	12 —	18	8½
Ditto,	ditto,	13 —	20	8¾
Ditto,	ditto,	14 —	24	9
Ditto,	ditto,	15 —	25	9

			Number of Seconds.	
			Horizontal Plane.	Curve.
Engine and carriage,	with	16 lbs.	could not go.	9¾
Ditto,	ditto,	17 —	. . . . . .	10¼
Ditto,	ditto,	18 —	. . . . . .	10½
Ditto,	ditto,	19 —	. . . . . .	11
Ditto,	ditto,	20 —	. . . . . .	11½
Ditto,	ditto,	21 —	. . . . . .	12
Ditto,	ditto,	22 —	. . . . . .	12½

In the preceding statement, the advantage offered by the curved Railway over the horizontal, is very decided; shewing an extraordinary difference in speed upon all occasions, and that 7 lbs. more could be conveyed upon the one than upon the other; 15 lbs. being the maximum weight that could be dragged upon the horizontal Railway, and 22 lbs. upon the curve; while, in the latter instance, the line was traversed in 12½ seconds, whereas upon the former it required 12½ seconds to take 9 lbs.

On trying how much greater weight could be taken up this incline, upon the irregular curved road, we found it to be as follows:

21 lbs. in 12 seconds.
22 lbs. in 13 seconds.
23 lbs. in 14½ seconds.
24 lbs. in 16 seconds, which was the maximum.

Being anxious to ascertain, if I reduced the rise of the 5-feet curve nearer to the level, what difference there would be in result, I ordered it to be planed down to a *one*-inch, instead of a two-inch curve; thinking it desirable to ascertain with how little declination the force of gravity, &c. could be rendered practically advantageous, and being of opinion, that the advantage over the horizontal Railway would be, even with the most trifling undulation, very important.

The following are the particulars of my experiments when this alteration was completed, and when all the Railways were nailed firmly down upon 3-inch planks, and when there was no possibility of vibration; the first series being tried on an exact level, and the last on an inclination of 1 in 96, which is the same ascent as the Rainhill incline, upon the Manchester and Liverpool line:

On a Perfect Level.

		Number of Seconds. Horizontal Plane.	5-feet Curve, rise, 1 inch.	Irregular Curve, rise, 2 inches.
Engine and carriage,	without load	5¼	4¾	4¾
Ditto, ditto,	with 5 lbs.	6¾	6	6
Ditto, ditto,	10 —	8¼	6¾	6½
Ditto, ditto,	15 —	9½	7½	7¾
Ditto, ditto,	20 —	11½	8½	7¾
Ditto, ditto,	25 —	13¼	9½	8½
Ditto, ditto,	30 —	15½	10	9
Ditto, ditto,	32½ —	18¼	10½	9½
Ditto, ditto,	35 —	20	11	10¼
Ditto, ditto,	37½ —	21¼	11½	10½
Ditto, ditto,	40 —	23½	12	10¾
Ditto, ditto,	42½ —	29	12½	12
Ditto, ditto,	45 —	....	13½	12¼
Ditto, ditto,	50 —	....	16	12½
Ditto, ditto,	55 —	....	19	17

Experiment up an Inclined Plane of 1 *in* 96.

		Horizontal Plane.	5-feet Curve, rise, 1 inch.	Irregular Curve, rise, 2 inches.
Engine and carriage,	without load	5½	4¾	4¾
Ditto, ditto,	with 2½lbs.	6½	5½	5½
Ditto, ditto,	5 —	7¼	6	6
Ditto, ditto,	7½ —	8¼	6½	6¼
Ditto, ditto,	10 —	9	7½	7
Ditto, ditto,	12½ —	11	8	7½
Ditto, ditto,	15 —	12½	8¾	8
Ditto, ditto,	17½ —	14	9½	9
Ditto, ditto,	20 —	15¾	11	10½
Ditto, ditto,	22½ —	19	12	11
Ditto, ditto,	24 —	27	12¾	12
Ditto, ditto,	25 —	would not go.	13	13
Ditto, ditto,	27½ —	....	16½	16
Ditto. ditto,	29 —	....	18¾	17

It is necessary to observe, that before trying the previous experiments, owing to the cord upon the spring-barrel having broken, I was compelled to re-attach it, and regulate the power of the spring accordingly, which will, in some measure, account for the increased speed upon all the Railways; and there being no longer the slightest vibration, and the level and incline having been most cautiously adjusted, I feel little hesitation in stating, that confidence may be placed in this published result of these experiments.

Referring to those on the level, it appears, that the speed on the irregular curve was greater than on the 5-feet curve, the amount of load capable of being conveyed on each being equal; whereas, on the incline of 1 in 96, so great an advantage did not appear, though both, *as in every other case*, proved far more effective than the horizontal Railway.

Referring, also, to the experiments tried upon an incline of 1 in 94 (page 69), we find that 15 lbs. was the maximum load conveyed upon the horizontal Railway; whereas, in the preceding statement (1 in 96), 24lbs. was conveyed in 27 seconds. This difference is no doubt attributable to the difference in the inclination, and to the renewed strength of the spring, as well as to the freedom from vibration.

Again, in the experiments upon the perfect level (page 67), it appears, that 30lbs. was the utmost load which could be conveyed on the horizontal Railway; whereas, in the preceding statement, 42¼ lbs. were conveyed in 26 seconds. This difference is in like manner accounted for.

In allusion to the comparative difference in the speed between the two curved Railways, in the preceding statement, and in the statement at page 67, I confess myself in difficulty, and can only account for it in the difference in the vibration of the two Railways, or to some inaccuracy in levelling, especially as, in the experiments at page 67, the depth of each curve was similar.

It may, probably, be thought unwise by some, that I should have published these conflicting statements; but I have considered it my duty to give a detailed and faithful account of my experiments, being sufficiently satisfied with the fact, *that, however different has been the comparative result of experiment between the two curved Railways, they have invariably, whether upon the level or incline, proved an unquestionable and decided superiority over the horizontal Railway.*

It will be seen, too, that in the experiments at page 67, where the inclination was 1 in $42\frac{2}{3}$, that the irregular curve was decidedly superior to the regular curve, both in speed, and in the amount of load capable of being conveyed upon it; whereas, in reference to the preceding statements (1 in 96), the results are altogether different; the advantage shewn on both curves, over the horizontal line, in the amount of weight conveyed, being nearly equal. This is more extraordinary, as the 5-feet curve had, in the recent experiments, been reduced 1 inch in depth; and I hold it an established principle, that in proportion to the length and depth of the descent, will be the proportion of advantage gained. I, therefore, expected a more favorable result from the irregular curve up the incline of 1 in 96, whose depth had not been altered.

On consideration of the subject, however, I decided, that the difference was attributable to the same causes as before stated in regard to the horizontal Railway, namely, to the difference of vibration, and to the extreme difficulty of levelling with perfect exactness upon an unequal floor, which, however particular I had been, had, no doubt, considerable effect, until I had the Railways affixed to strong 3-inch planks, which planks were levelled, or inclined, with greater precision and ease.

Perceiving, also, that in the irregular curve the abruptness of ascent was, when heavy weights were attached, a considerable obstacle, I ordered them to be planed down, so as to make the ascent 4 feet instead of 2, and, consequently, the depth of descent 1½ inches instead of 2.

The result of the following experiment proves, that the speed of conveyance upon the two undulating lines, when upon a level, more nearly assimilated; and that the abruptness of ascent being removed, a greater weight could be conveyed upon the 6 and 4-feet curve (altered from 8 and 2 feet), depth of descent 1½ inches, than upon the regular 5-feet curve, depth of descent 1 inch.

Hence I am led to the conclusion, that whether, in practice, it may be found better or not, to adopt undulating Railways with short ascents and long descents, or with the ascents and descents proportionate, as regular curves; the advantage gained over a common horizontal Railway will be in proportion to the length and depth of descent; taking care *never to have the ascents so short as to render them abrupt, nor the descents so deep as to render them dangerous.*

Experiment on a Perfect Level.

			Irregular Curve, 4 feet ascent, depth of descent $1\frac{1}{2}$ inch.	5-feet Curve, as before.
			Seconds.	Seconds.
Engine and carriage			$4\frac{3}{4}$	$4\frac{3}{4}$
Ditto,	ditto, with 5 lbs.		$5\frac{1}{2}$	6
Ditto,	ditto,	10 —	$6\frac{1}{4}$	$6\frac{3}{4}$
Ditto,	ditto,	15 —	$7\frac{1}{4}$	$7\frac{1}{2}$
Ditto,	ditto,	20 —	$8\frac{1}{2}$	$8\frac{1}{2}$
Ditto,	ditto,	25 —	$9\frac{1}{8}$	$9\frac{1}{8}$
Ditto,	ditto,	30 —	10	10
Ditto,	ditto,	35 —	11	11
Ditto,	ditto,	40 —	12	12
Ditto,	ditto,	50 —	$14\frac{1}{2}$	16
Ditto,	ditto,	55 —	$15\frac{1}{4}$	19
Ditto,	ditto,	59 —	20	

Having thus submitted to public notice, the particulars of my experiments, by which it is distinctly proved, that a curved line of Railway presents the most undoubted advantages over a horizontal one, for the rapid conveyance thereon of merchandise and passengers, and for the effective and economical exercise of locomotive power, few observations are necessary, beyond those I have already made, to make evident the cause of this advantage, which altogether results from rendering the power of gravity, which is a natural motive power, or the accumulation of velocity and momentum produced thereby, applicable to a *most important purpose;* and I confidently believe, that such assistant power being taken advantage of on Railways, any locomotive steam-engine (assisting gravity down each descent, and opposing it up each ascent) will traverse a given space, when drawing what may be, at the present time, deemed its full load upon a horizontal line, in *half the time* which it could otherwise do, or will, *in the same time*, convey *twice the weight* of merchandise. It must be borne in mind, *that the previous experiments have been tried with a power not sufficient to overcome the friction of the periphery of the wheels of the engine upon the plane, when stopped from progressing: I look, therefore, to a far more advantageous result than is thereby shewn, when, upon a regular line of road, efficient* *steam power can be employed—a result which cannot fail, in my opinion, to be peculiarly advantageous in the ascent of inclined planes.*

To state, from the preceding experiments, what the exact amount of advantage is, would be difficult, as it varied with different loads; but, referring to those trials which are last detailed, and which were made with a strengthened spring, on the perfect level, and when the roads were free from vibration; and taking 30lbs. as the medium weight the engine conveyed on the level, and 15lbs. upon the incline of 1 in 96, we have as follows:

Weight carried.	Average on the two Curves.	On the Horizontal Plane.	Length of Lines.
lbs.	Seconds.	Seconds.	Feet.
30	$9\frac{1}{2}$	$15\frac{1}{2}$	32

$$9\tfrac{1}{2} : 32 :: 15\tfrac{1}{2} : 52\tfrac{4}{19};$$

shewing an advantage of full 5-8ths on the level.

Weight carried on Incline.	Average on the Curves.	On the Horizontal Plane.
15lbs.	$8\frac{1}{2}$ seconds.	$12\frac{1}{2}$ seconds.

$$8\tfrac{1}{2} : 32 :: 12\tfrac{1}{2} : 47\tfrac{1}{17};$$

shewing an advantage of very nearly *one half*.

It must not, however, in this calculation of advantage, be overlooked, that the *comparative* advantage increased with *every increase of load*, and that, exclusive of this advantage in speed, was the capability of conveying, with the same power, a much heavier load upon the undulating than upon the horizontal Railway.

Being desirous, if possible, of laying before the public an unobjectionable and practical proof of the advantage above stated, it occurred to me, that I might do so by giving a *limited* power to the engine, and by seeing what difference there was in the momentum gained upon the curved and horizontal lines.

For this purpose I wound up the spring, by drawing the engine-wheels back exactly *six feet;* and loading the carriage with 30lbs.

Upon the horizontal road it traversed with this power,
7 feet 9 inches = 1 foot 9 inches momentum.

Upon the curve,
10 feet 2 inches = 4 feet momentum.

Again, on winding up the spring equal exactly to 10 feet, it traversed, with 30lbs.

On the horizontal plane, in 12 seconds,
14 feet 7 inches = 4 feet 7 inches momentum.

On the curve, in 10 seconds,
20 feet = 10 feet momentum.

Loaded with 20lbs. and wound up 10 feet, it traversed,

On the horizontal plane, in 13 seconds,
20 feet 8 inches = 10 feet 8 inches momentum.

On the curve, in 12½ seconds,
28 feet 4 inches = 18 feet 4 inches momentum.

Without load, and trying the engine and carriage alone, the spring being wound up 6 feet, the result was as follows:

On the level,
17 feet 9 inches = 11 feet 9 inches momentum.

On the curve,
21 feet 11 inches = 15 feet 11 inches momentum.

I was induced to try these latter experiments, not with the view of corroborating the *exact* amount of advantage proved by the previous trials, but to offer decided proof of the *cause* of that advantage, the maximum of which would of course depend upon the uniform action of gravity and power: for instance, when the spring was wound up 6 feet, and the carriage loaded with 30lbs. the difference in space traversed, was as 93 inches to 122; but when the spring was wound up 10 feet, and the carriage similarly laden, the difference in space traversed, was as 175 to 240; shewing very different proportions.

From a careful examination of all the previous experiments, it cannot possibly be doubted, that Nature presents to us, in gravity, a most important assistant power, which, united with mechanical power, will not only enable us to travel with far greater speed, and with far greater loads, but renders locomotive power far more effectively applicable.

How little the laws of motion upon Railways are at this moment understood, may in some measure be judged of, by the remarks of Mr. Nicholas Wood, who seems to express a doubt whether,

1st, According to the general received opinion, the intensity of power required to keep a body in motion at twice the velocity, should be twice that required to keep it in constant motion at half that velocity—as,

Supposing velocity to be represented by	1,	2,	3,	4,	5,	6
Distance passed over . .	1,	1,	1,	1,	1,	1
Power required to move a carriage of any weight	10,	20,	30,	40,	50,	60

Or,

2ndly, Whether the intensity of power required to urge the body forward at twice the velocity, is not four times that which is required to keep that body in motion at half the velocity—as,

Velocity, V, at which the body is moved	1, 2, 3, 4
Resistance of body, B	10, 20, 30, 40
Space passed over	1, 1, 1, 1
Mechanical force required to propel B over S, at velocity V . . .	10, 40, 90, 160

Or,

3rdly, Whether the intensity of power required to urge the body forward, is not in the ratio of the square of the velocity—as,

V	1, 2, 3, 4
B	10, 40, 90, 160
S	1, 1, 1, 1
Mechanical force . . .	10, 80, 270, 640

I feel little hesitation in discarding the two last positions, and in founding my belief upon the first position.

Now, if this position be correct, viz. that it requires *twice* the mechanical power to move a body 20 miles per hour than to move it 10 miles per hour, upon a horizontal Railway, how evident is the advantage derivable from the curved line of road, when a given power being employed to move a weight of 40lbs. 32 feet upon a horizontal plane in 21 seconds, moved on the curve the very same weight, the same distance, in 10½ seconds; shewing, that the power of gravity, multiplied by any given mechanical power, is fully equal, when made jointly available, to compensate for the loss of mechanical power sustained upon a horizontal plane by a doubled velocity!

It would be extremely desirable to reduce the laws of locomotion and friction to some decided data. The difficulty of doing this, is not only evident from the diversity of opinion in regard to the latter, which has so long existed, but, after a series of most interesting experiments upon Railways, Mr. Wood himself, to whom we are indebted for much valuable and practical information, confesses, that such is the difficulty of the subject, that, although his experiments may be sufficient, in many cases, for practical purposes; "yet they by no means tend to bring the "enquiry into any more settled state."

Much, however, as I appreciate the talent and public services of Mr. Wood, I cannot avoid mentioning, that he appears to me to have laboured under a mistake in some of his calculations; for instance (page 202, second edition), he calculates the resistance *up* a plane to be a given amount, say 56, and down the plane a given amount, say 22, and then draws his mean resistance, or friction, upon a level plane, 39—thus:

$$\frac{56 + 22}{2} = 39.$$

Now, I dispute the correctness of this mode of ascertaining the mean resistance on a level, inasmuch as the power of gravity, assisted or not by mechanical power, down a descent, being a constantly accumulating power, diminishing resistance,—and when a given power is employed to drag a body *up* a plane, the resistance being uniform through every space and time,—the two powers of resistance added together and divided, cannot shew the mean resistance on a level, and for the reasons before stated in page 47.

I name this, because it particularly bears upon the principle on which I found my improvement; for, if Mr. Wood be correct, it appears to me impossible that any advantage could accrue from the adoption of a curved or undulating line of road; whereas, experiments corroborate my assertion, that such advantage is indisputable. The power of gravity, which produces accelerated velocity down the descending part of a curve, may be said to be counterbalanced by the opposing power of gravity up the ascending part; but we must not forget, that before the ascent commences, a given power or momentum is generated, and a given space must be travelled over before this power becomes inert; and as gravity alone thus enables a load to descend an inclined plane, and to ascend an opposite one until momentum cease, it is evident, that, locomotive power being employed *from such point of stoppage to the highest summit of ascent*, the number of the revolutions of the axles and of the wheels upon the plane, must necessarily be considerably less than along a level line proportionate to the extent of the curve. It must also be evident, that, either on the descending or ascending line of a curve, the axle and rolling friction must be less than upon a horizontal plane, inasmuch as the line of gravity *is never vertical*, except at the lowest point of descent and the highest point of ascent; whereas upon the horizontal plane it is *continually* so.

It is true, that the power of gravity has been applied to Railways in many useful ways; such as the loaded descending carriages drawing the empty carriages up an incline, &c. &c.; but how little it has been thought of as an assistant to locomotive power, will appear from Mr. Wood's remarks: "On public, and other Railroads, "where the quantity of goods to be conveyed "is fluctuating, and is, or is likely to be, the "same in both directions, this species of "power cannot be resorted to."

Again, "It is only where a preponderance "of goods has to be conveyed in one direc-"tion, and where, upon any declivities oc-"curring in the line of road, that prepon-"derance is capable of overcoming the gravity "of the returning carriages, that the action "of gravity can be used to advantage."

This is quite true, in regard to a descending body drawing up an ascending body; the former must be heavier than the latter; but apply mechanical power to each, and that which will be requisite to propel the carriage down the plane, will be much less, as before observed, in proportion to what would be required upon the level to move the same load, than the amount of power necessary to move the carriages *up* the incline, above that employed upon the level.

With these explanations, I shall content myself with laying down what appear to me a few leading principles, in reference to this subject: results will prove how far they are correct.

1. *That the friction of carriages upon all Railroads, is in proportion to their weight, and the diameters of their wheels and axles; and when propelled by any constant power, this friction is an* uniformly active force.
2. *That the load which a locomotive engine can convey,—or, in other words, the amount of steam power which can be rendered effective on a horizontal Railway,—is always in proportion to the weight of the engine, or the friction produced thereby.*
3. *That the difference in load which a loco-*

motive engine will convey up an inclined plane and on a level,—or the amount of steam power which can be rendered effective on each,—is in proportion to the inclination of the plane.

4. *That the difference in load which a locomotive engine will convey down an inclined plane and on a level, can form no basis whatever for the calculation of friction, or speed, upon a level, inasmuch as the load never can be too excessive for the engine down the plane; and the momentum gained from the effect of constant mechanical power, in addition to gravity, accumulates in exact accordance with the laws which govern gravity.*

5. *That if it require a given power to move a body* 10 *miles per hour, at maximum velocity, upon a horizontal Railway, it will require twice that power to move the same body* 20 *miles per hour.*

6. *That the same law governs the motion of bodies up inclined planes*.*

7. *That the same law does not apply in any degree to the motion of bodies down inclined planes, inasmuch as, whatever be the power employed, the spaces over which the body will travel, will be as the squares of the times from the commencement of the descent.*

8. *That, upon the above principles, a much greater speed can be attained by the exertion of a given power, or a much greater load carried by that power, upon a curved† or undulating Railway, than upon a horizontal plane.*

* I mention this as an established principle, in reference to all useful purposes; although it may be argued, that the higher the ascent, the less becomes the power of gravity. Such difference is, however, as before stated, altogether immaterial.

† It is obvious, that a continuation of inclined planes, gradually curved at their bases and summits, would prove quite as, if not more effective than, regular curves, or segments of circles. Cycloids may, in practice, be found the most advantageous description of curves.

9. *That the maximum speed which can be attained, and the maximum load which can be dragged by a given locomotive power, upon a curved line, depends upon the length and depth of the curve; consequently, the longer and deeper the descent, though the rise be equal to the fall*, the greater the advantage.*

10. *That in the ascent of inclined planes on a curved line of road, the depth of each curve,—or, in other words, the angle of each descent,—should always exceed the angle of the inclined plane.*

11. *That it requires a greater power to move a body from a state of rest to a given state of motion, than to keep it in that state of motion when such motion is attained.*

* As before observed, it is a matter of future experiment, how far short, may be more advantageous than long ascents, though the height of ascent may be equal to the depth of descent; my opinion is, that they will prove the most effectual.

12. *That the momentum of a moving body is exactly as the velocity of the body multiplied by its weight.*

13. *That such momentum, when produced by any given power, on a horizontal Railway, is equal to the difference between the force required to move a body from a state of rest to a given uniform velocity, and the force required to keep such body in motion, at such given attained velocity.*

In reference to Definition 13, let P represent the power required to keep a body, B, in motion at the velocity expressed by V, and P′ the power required to move the body from its state of rest to the required velocity, and let M represent the momentum of the body when the velocity is acquired; then,

$$M = P' - P;$$

or, supposing it require 10 lbs. to move B from a state of rest to a given velocity, and

8 lbs. to keep it in motion when such velocity is acquired; then,

$$M = 10 - 8 = 2.$$

Referring to Definitions 4, 5, 6, 7, it will be seen, that upon them the superiority of the curved or undulating Railway over the horizontal Railway, in a great measure depends; for it is by the accumulation of speed down each descent, and the increased momentum by the accumulative force of gravity, multiplied by mechanical power, that overcomes the chief resistance of each ascent, and thereby produces the advantage which I have endeavoured to explain, and which I affirm to be obtained upon a curved Railway. How far that advantage may be increased by making the length of ascent shorter than the length of descent, I will not now discuss; I am inclined, however, to think it will prove considerable, as the power of steam would thereby be more effectively employed, by working more constantly on the descent, where the retarding force of friction is necessarily less, and the fulcrum presented to the activity of steam power greater than on a level, and where the gravity of the descending carriages would more than compensate for the loss of power, by the comparative steepness of the ascent.

Having thus far treated of the advantages likely to accrue from the adoption of my improved Railway,—advantages as clearly demonstrable, in my opinion, by figures and mathematical reasoning, as by experiment,—I now proceed to anticipate and to answer such objections as may naturally arise in the public mind, on a perusal of these pages.

1.—*The Motion may be Inconvenient and Unpleasant.*

This is altogether ideal; even if the curves were deep and short, I much question whether the motion would not be found rather agreeable than otherwise. Any one who has travelled in a carriage upon an undulating surface of turf, may form some opinion of what it would be upon a deeply-curved Railway; but as the curve upon which the preceding experiments were principally tried, is only 1 inch in 5 feet, and supposing 100 feet, upon a regular line of road, rising and falling 20 inches, or 100 yards rising and falling 5 feet, to be a sufficient extent of curve for practical purposes,—it will be evident, that the undulating motion could not produce any serious inconvenience. Indeed, whether the curve be longer or shorter, the motion, in my opinion, and in the opinion of those who have witnessed the experiments, would be any thing but objectionable; for in short curves, any very deep undulation would be unnecessary, and in long ones, comparatively unfelt. To ascertain, however, the most advantageous description and extent of undulation, must be the object and result of careful practical experiment. Allowing my principle to be correct, the difficulties of practice are easily overcome.

2.—*The Difficulty of Ascent, provided the Engine should stop, by accident or otherwise, at the Base, or in other particular part of the Curve.*

I am of opinion, that it will be found desirable, at all parts of the line where a train is intended to stop, to have the road for a short distance perfectly level, though I do not conceive that any practical difficulty would arise were it not so. I would also recommend the same level road, for any required length, at the places of starting.

But let us take the worst view of the question, and suppose the carriages to stop in such a position, and to be so laden, that the engine could not rise the ascending part of the undulation.

It will be evident, as a locomotive engine can be worked either backwards or forwards, that, by reversing the action of the power, the carriages will be driven back by that power, and their own gravity, sufficiently high up the opposite incline to give them in a few moments the full power of progression.

This is, however, supposing a case which will seldom or ever, I should think, occur; as it would be just as easy to stop the train when the engine was at the bottom or other part of the ascent, with the gravity of the following carriages at disposal to assist the rise, as when the whole train were ascending: the necessity of this, however, depends upon whether the engine be overladen or not. I am only anxious to prove, that, let the load be what it may, if once capable of progressing, it never can be delayed beyond a few minutes upon an undulated line of road; and *that delay* the engines are *now* subject to, in acquiring their average velocity upon a common Railway.

There are no other objections which arise in my mind to the general adoption of undulating Railways; and if there be, how little do they depreciate the advantages offered by the increased speed, and the economy of power which I have proved to be derivable from them, added to the facility of ascending inclined planes, the reduction in the expense of excavations, and other advantages!

I am aware that many plans have been suggested of ascending inclined planes, by friction-wheels, &c. &c.; but Nature presents us with so powerful an assistant, in gravity, and at so little expense, that it would be madness to refuse her aid.

I have merely now to add, that, in the experiments which I have tried, the loads were attached to the engine by means of a metal rod, with a moveable joint at each end, something similar to the one described in *fig.* 2; and whether, upon the lines of road now established, such mode of connecting the carriages be thought advisable or not, instead of by the chains now employed, it will be very desirable that such should be the case upon the undulating lines, as the gravity of the descending load is a principal and indispensable advantage, which, were it attached to the engine by chains, would be comparatively lost, as, in the ascents, the unpleasant jerks I am so anxious to obviate, might be even more objectionable than they now are.

I have also to add, that should the ascents (as locks, bridges, &c.) on canal-lines, or other roads, be so steep as to become inconvenient for the effective exercise of locomotive power, and for the progress of the train, it may probably be found desirable, to obviate the expense of levelling, to have *stationary weights* so constructed as to be drawn either up or down the inclined planes; acting, in their ascent, as a lock for the engine and carriages down the hill, and in their descent, as an assistant to the rise of the engine and carriages up the hill. The gravity of each of these weights might be such as to act beneficially upon all average loads; indeed, the same weights might be so regulated, *by machinery at the top of each ascent*, as, without the employment of a stationary steam-engine, to *accommodate themselves* to *different loads;* supposing, which I do, that a suitable person be employed to attend to them, and that the trains of carriages are traversing the roads each way in pretty equal succession. This, however, can only be necessary where the momentum required to assist the engine and load up any ascent is such as to produce a velocity dangerous to passengers.

In conclusion, as I have reason to believe that I may soon have an opportunity of practically proving the importance of the improvement which I have promulgated in this short Treatise, and the extent of the advantage I anticipate, I will only add, that it is my intention, at such time, to pursue the subject by a second publication; in the interim, offering this to an enlightened and reflecting Public, with humble confidence.

ADDITIONAL REMARKS.

ADDITIONAL REMARKS.

THE publication of the preceding pages having been unavoidably delayed much longer than I anticipated, and having had an opportunity in the meantime of trying a series of experiments upon models of a more extended scale than those to which I have hitherto referred, I am happy in being able to state, that the result has been equally favorable to my expectations in every point of view.

The models in question have been for some weeks open to the inspection of the scientific world, and the experiments have been witnessed in London and at Manchester by numerous individuals, whose high mathematical and mechanical acquirements would, I conceive, naturally have led to the immediate exposure of a fallacy, had any such fallacy existed. On the contrary, however, the facts elucidated by experiment remain uncontroverted; and although it may have proved difficult to *some* to account satisfactorily and theoretically for the advantage gained, yet I am happy, on the other hand, in being able to state, that I have received, from *other* unquestionable authorities, assurances of their conviction, that the principle which forms the leading subject of this Treatise, is a correct one, and that, however opposed to received opinion, it is in strict accordance with true mechanical and mathematical reasoning.

It would, I confess, have very much relieved the responsibility which I incur in offering this publication to the world, had I felt myself at liberty to embody the various correspondence, formula, diagrams, and calculations, with which I have been favored, in solution of this, I trust, important subject: but, fully sensible of the averseness which men naturally feel in permitting others to make public their friendly opinions, I, from delicacy, abstain from stamping a value upon this Work, which would, otherwise, have raised it much higher in public estimation than any observations which I feel it in my power to offer.

I shall therefore content myself by adding hereto, in a more compressed and mathematical form than I have hitherto done, a statement of my own opinion as to the cause of advantage derivable from a curved or undulating Railway; to which I shall annex, by permission, the Reports of Mr. Robert Stephenson, senior, who, although prevented by indisposition from witnessing the experiments, favored me some months ago with his opinions;—to which I am also desirous to attach an article upon an Improved Axletree, published by that Gentleman in the 66th Number of "The London Journal of Arts and Sciences," in the year 1826 (the particulars of his invention appearing in the same Number), especially as this improvement will, in my opinion, be found particularly applicable to carriages working upon an undulating line of road; as, were the common axletrees to be used upon such Railway, they would, where the lateral curves or windings are abrupt, no doubt materially interfere with the advantage I expect to derive from the full combined effect of gravity and locomotive power; whereas, by adopting the axletrees recommended by Mr. R. Stephenson, senior, the advantage would, in comparison with existing roads, be as great upon a *winding* as upon a *direct* undulating Railway.

The following is my explanation, which, I conceive, bears me out in all my previous remarks:

Suppose the dotted line, E A, to be a horizontal Railway,—A B, to be a descend-

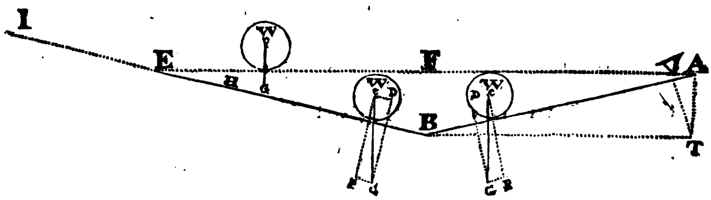

Fig. 10.

ing one,—and B E, an ascending one, on which are placed the three wheels, W W W.

1. Now, the amount of friction produced by the pressure of the wheel W on the plane E A, is in exact proportion to its weight, or to the weight of any vehicle which rests upon it; and upon such weight also depends the amount of attrition produced by the revolution of the axle within the nave or cylinder in which it moves.

The reason why the amount of friction, or attrition, is proportionate to the weight of the vehicle, is because (supposing C to be the axle, or centre, of the wheel), the perpendicular line, C G, is the line of gravity.

On a horizontal Railway, therefore, the amount of pressure upon the rails, and the amount of axle and rolling friction produced by that pressure, are in exact accordance with, and altogether dependant upon, the weight of the carriages and load; and when locomotive power is employed to overcome this pressure and friction, and when a maximum velocity is attained; such velocity (the power being kept up) is uniform through spaces and times, and such pressure, or friction, is an *uniformly opposing power*. Moreover, as before frequently observed, the amount of load which any locomotive engine will convey, is in exact accordance with the amount of its pressure upon the rails and axles; or, in other words, with the axle and rolling friction.

2. Let us now suppose the wheel W to be

traversing from A to B. From the point A, it is evident that a body would fall to T, according to the laws of bodies falling perpendicularly; and if upon the line A B we draw the perpendicular line V T, a body would descend, by gravity, down the plane from A to V, in the same time as it would fall, perpendicularly, from A to T: and the power of gravity, which enables it to do this, acting *equally* (practically speaking) throughout the whole descent from A to B, would produce *an uniformly accelerated motion;* in consequence of which, on the arrival of the carriage at the point B, the velocity would (allowing for the difference of friction) be mathematically equal to what it would be at the point T, had it fallen perpendicularly from A to that point. Now the extent of the power of gravity, or cause of the wheel W descending down the incline A B, will be easily comprehended by reference to the parallelogram, D C P G: where the diagonal, C G, is the line of gravity, C P the line representing the amount of pressure on the rail, and C D the line of motion;—that is, the line or power of gravity, C G, instead of acting perpendicularly, and with full intensity, on the rail, as on the line E A, becomes divided into two separate and distinct powers, viz. C D and C P; the latter, if I may so express myself, endeavouring to stop the progress of the wheel, and the former employing every effort to urge it forward; and as C D is to C P, so is the one power exactly to the other;—and thus, if the carriage or wheel, W, weigh 5 tons, and if C D be 1-5th of the power or force, C P, the pressure upon the rails is reduced from 5 tons to 4 tons; and *not only reduced*, but the amount of power thus saved, is actively employed in opposing the resistance offered by C P.

Such would be the *commencement* of the progress of a carriage descending the incline A B, by its own gravity, until, as before observed, on arriving at B, it would attain the same velocity as it would have attained at T, had it fallen perpendicularly from A to T; and if locomotive power were constantly employed to assist this force of gravity, the progress of a body down the descent would be the result of these united powers; the motion would be *uniformly accelerated*, and although the velocity would be increased in proportion to the increased power employed, yet the descent would be in proportionate accordance with the laws of falling bodies, both as to spaces and times.

3. But we will now suppose the same carriage, W, to be propelled from a state of rest at B, to the position on the

incline B E, described in the diagram. The angle F E B being equal to the angle F A B, and the line of gravity, C G, being drawn, the parallelogram, C D G P, is exactly equal to that described on the descending plane; consequently, C P is the line representing the amount of pressure on the rails, and C D the line of power opposing such pressure; from which it is evident, that, unless prevented by some greater power than C D, the carriage would roll back to B, but if opposed by any regular and greater power, which we will call locomotive power, the carriage would rise gradually up the plane B E, with uniform velocity, and through equal spaces in equal times; for the power C D, which is a portion of the force of gravity represented by C G, *being opposed by a greater power* than itself, does not in this case act as *an uniformly retarding* *power*, but as *an uniformly opposing power*. It will also be seen, that, throughout the ascent, the pressure upon the rails, and, consequently, the amount of friction, is precisely the same as it was down the descent A B, viz. as much less than it was on the horizontal line E A, as the line C D to D G.

4. But to prove the advantage to be derived by an undulating Railway, we must not allow the carriage to stop at B; we will therefore suppose it to travel as far as it is able, by gravity alone, along the undulated line A B E.

Now, as before observed, it would descend from A to B, according to the laws of falling bodies, at which point will have attained its greatest speed, and, consequently, its greatest momentum, and it is evident that it will rise the ascent B E, as long as the force of momentum is greater than the force C D; but the instant such force of momentum, which in this case is ***an uniformly retarding force***, becomes less than the force C D, the latter would effectually operate, and the carriage, W, would roll back, and finally settle at the point B.

Supposing, however, that the momentum gained by the descent to B, be sufficient to advance the carriage as far up the ascent as the point H,—it is evident, that, could sufficient power be ***then*** employed, to overcome C D, the ascent H E would be made in much less time, with fewer revolutions of the wheels and axles, and with much less expense of power, than it would require to move up the whole ascent B E, as stated in Position 3.

We will now suppose, that an assistant power, equal to the available power C D, be employed to propel the carriage, W, along the undulation A B E, and that such power were withdrawn at the point B,—it becomes evident that, as *gravity alone* enabled the carriage to rise the ascent as far as H, which is more than one-half of the whole ascent, now that double power is employed, double momentum at the point B will be the result; and the power C D will thus effectually be opposed up the whole ascent B E. If this be true, how much more effectually will the power C D be counteracted, if the assistant power be continued up the whole ascent B E!

From this reasoning, it appears to me indisputable, as decidedly proved by experiment, that not only can a given load be conveyed along a curved line in *very much less* time than upon a horizontal plane, or *a very much greater weight* in the same time, but that loads which no locomotive power could move on the horizontal plane E A, would, impelled by gravity, assisted by other active power, descend down A B, and rise the ascent B E, with facility; and it will be also evident, that whatever power may be left on arriving at the point E, will be the power of ascending the farther incline E I; to which surplus must of course be added, the continued active power employed to oppose C D.

5. It must be remarked, that although the disposable *power* of gravity, in opposition to pressure, is only as C D to C P, yet this is no criterion of the extent of advantage gained in speed; in fact, CD may as properly be stated to represent the saving in friction: in whatever light, however, it may be viewed, C D represents a *constant* and *equal* power throughout the whole descent; but the spaces passed over down that descent, in consequence

of such power, are *not* equal in equal times, but, owing to accelerated velocity, as the squares of the times. Supposing, for instance, A V to be 10 yards, and the carriage was 1 second in reaching V, and allow the same space to be travelled over on the horizontal plane in the same time, at maximum velocity,—now, on the latter, the carriage would travel 30 yards in 3 seconds; but down A B it would travel 90 yards in 3 seconds; because $3 \times 3 \times 10 = 90$; and this velocity, although retarding up the ascent, if assisted by an equal power to that employed on the horizontal plane, would be so kept up, as to arrive at a given distance in far less time than it could do, with an average load, on the horizontal plane. Supposing, for instance, the horizontal line E A were 175 yards long, the descent A B 90 yards, and the ascent B E 90 yards, making the undulating line 180 yards, and that locomotive power were employed, sufficient to overcome the friction and the resistance of the atmosphere on both lines, and to move a carriage along E A, at maximum velocity, 10 yards per second: it is obvious, that the time required to travel from E to A, would be 17½ seconds; because $\frac{175}{10} = 17\frac{1}{2}$.

Let us now apply the same power to the same carriage travelling along the undulation A B E, and take 10 yards as the space travelled over in the first second down the descent A B: it is obvious, that it would reach the point B, or, in other words, traverse the 90 yards represented by A B, in 3 seconds; because, according to the laws of descending bodies, $3 \times 3 \times 10 = 90$. This being admitted, and even presuming that the power employed up the ascending part of the undulation, were *only just* sufficient to *overcome* the friction and resistance of the atmosphere, the carriage would naturally, as proved by the action of the pendulum, rise the ascent B E in the precise time it occupied in traversing from A to B. Hence, if a given power be employed, sufficient to overcome the friction and resistance of atmosphere, and to impel a load 10 yards in the first second, upon an undulating line, such as A B E, 180 yards in length, the whole distance, if the power be constantly kept up, will be traversed in *less* than 6 seconds; whereas, if a given power be employed, sufficient to overcome the friction and resistance of atmosphere, and to impel a load 10 yards in the first second of time, *at maximum velocity*, upon a horizontal line, such as E A, 175 yards in length, the whole distance cannot be traversed in less time than 17½ seconds.

Thus, if we ascertain the maximum velocity at which a body can be impelled upon a horizontal line *in the first* second, and down the descending part of a given curve in the first second, such power being sufficient to overcome friction in both cases, the comparative time occupied in traversing each distance, is easily determinable; the difference in advantage varying in proportion to the length and depth of undulation, as compared with the length of the horizontal line. Nor must it be overlooked, in considering this subject, that a much greater load can be conveyed along an undulating line than along a horizontal one. The axle and rolling friction to be overcome, is necessarily less upon the former than upon the latter, and the fulcrum presented to the effective power of steam, down the descending part of each undulation, is a most important object of advantage. It will be seen, that in this explanation I have calculated the velocity of a body traversing a curve, according to the laws which would govern its descent down a regular inclined plane; there would of course be some difference, but in this instance it cannot be material to describe it.

ENUMERATION

OF

THE ADVANTAGES WHICH I PREDICT WILL BE DERIVABLE FROM THE ADOPTION OF UNDULATING OR SERPENTINE RAILWAYS.

1.

A great gain in speed.

2.

A great saving of power.

3.

A great saving in the expense of excavating, levelling, &c.

4.

The much greater facility with which inclined planes can be ascended.

5.

The strength of the rails, and, consequently, their cost, will be considerably diminished, or, if not diminished, there will be a great saving in their wear.

6.

That lighter and less expensive locomotive engines may be advantageously used.

7.

That much greater activity can be given to the effective power of steam.

8.

That the motion of the carriages will be easier, and more free from vibration, than upon a horizontal Railway.

9.

That the carriages may be attached together by moveable joints, instead of chains, so as to obviate the disagreeable jolting which is now so frequently experienced.

10.

That serpentine or undulating Railways can be laid down with advantage across a country where horizontal ones would be altogether inapplicable.

11.

That the necessity of crossing turnpike or other roads, will be obviated; as bridges could, in most cases, be constructed, over which the carriages might proceed, without the employment of stationary engines; and canals might be crossed in a similar manner.

APPENDIX.

K

APPENDIX.

Copy of Mr. Robt. Stephenson, *Senior's, First Report to Mr.* Badnall, *on the subject of his Undulating Railway.*

" *Pendleton Colliery,*
" *Sept.* 11, 1832.

" Mr. Badnall.

" SIR,

" Since I had the pleasure of your " company yesterday, I have been very much en- " gaged; but, according to your request, the time " I have had to spare, has been employed in " trying to establish some true cause why the un- " dulating Railway will be superior to the hori- " zontal one. To make it short, I will suppose a " carriage, four tons weight, regularly distributed " amongst the four wheels, and placed on the level: " now, if we hang two plumb-lines from the centre " of the axles, by their own gravity they will pass " on the inside of the centre of that part of the peri- " phery of the wheels in contact with the rails, and " each plummet-weight will apply its power to turn " the wheels; but they being applied in opposite " directions, the carriage will remain stationary.

" Now, let us lower one end of the same carriage " to the desired angle of the descending part of your " road; the plumb-lines being still attached to the " centres of the axles, and acting by the laws of " gravity, they will pass considerably on one side of

"the centre of that part of the periphery in contact
"with the rails; the great portion of the weight on
"one pair of the wheels is therefore taken off, and
"conveyed towards the other *axles;* and it is my
"opinion, that four tons are not now resting on the
"four wheels as before, but a portion of the whole
"is called into *motive* action, and will proceed
"down the incline, according to the laws of falling
"bodies, to the foot of the plane, with this *addi-*
"*tional* advantage,—the wheels being now in motion,
"will call into action the power of rolling force*,
"which will begin near to the resting part of the
"periphery of the wheels in contact with the rails.
"This being allowed, viz. that the force begins at

* Since this Report was written, I have had various conversations with Mr. R. Stephenson, senior, on the subject of the *force* to which he here alludes, and I confess myself inclined to attach considerable weight to his opinion. If I may be pardoned the invention of a word, I would term it, "*periphfugal force;*" inasmuch as it commences at the point where the wheel is in contact with the rail,—it increases or gathers to the extreme part of the wheel, and is all thrown off between that extreme part and the point where it again comes in contact with the rail. To demonstrate its effect, Mr. Perkins suggested that a wheel, *not* in contact with the earth, should be put in very rapid motion, and, when in such state of motion, be allowed to fall with its periphery in contact with a level plane; the result would be, that although no power were employed to urge it in a forward direction, it would continue to roll along the plane until motion ceased; evidently proving, that the centrifugal force, equally distributed through every particle of matter in a fly-wheel, is very different in effect to the force gathered and thrown off when such fly-wheel, in a state of rapid motion, comes in contact with the earth: in the latter case, the *point of contact* should be regarded as an ever-changing centre, from which the force originates, without any regard to centrifugal force, as commonly understood in reference to a revolving wheel. Such, at least, are my present, perhaps imperfect, ideas on this subject.—R. B.

" this point, it will certainly increase its power to " the extreme part of the wheels; the force will " commence throwing off immediately after passing " this extreme point, and will be all discharged " between that point and the rails, when it becomes " *inactive*. By this I mean, that the wheels are con- " stantly taking up power *on one side*, and throwing " off on the other, nearly between that part of the " wheel which is moving fast, and that which is " moving slow; in consequence of which, it will " have a great tendency to raise the wheel from the " rails, and, at the same time, will assist in the " progress of the forward direction; it will also " prevent the wheels from being pressed so much " *oval*, and indented so far in the rails, and *very* " *much reduce the friction*.

" This sort of force, perhaps, not being thoroughly " understood, you will allow me to compare it to " a man on horseback, riding at a great speed, and " the animal stopping himself with all the power he " is master of; we should, in such a case, naturally " expect to see the rider thrown forward, taking " along with him both bridle and stirrups.

" My time being so limited, I cannot at present " proceed further on the subject; and, in the interim,

" I am,

" Yours, respectfully,

(Signed) " R. STEPHENSON, Sen.

" P.S.—It has never been my opinion, that falling " bodies have been exactly attracted to the centre " of the earth.—R. S."

Second Report of Mr. R. STEPHENSON, *Senior.*

" *Pendleton Colliery,*
" *Sept.* 13, 1832.

" MR. BADNALL.

" SIR,

" IN my Letter to you on the 11th inst. " respecting your Railway, I think I left off at the " bottom of the first inclined plane. At this part, " the carriages will have attained their greatest " speed; the wheels will also be acting with their " greatest power; I mean as to rolling force. Here " it would require too much of my time to calcu- " late the required strength of the rails over this " part, and particularly at the beginning of the " next angle; but I will venture to say, the load " will not be so heavy on the rails, as many, at " first sight, would anticipate. It will be impos- " sible for me to tell exactly, until I have ascer- " tained, what power the wheels throw off at dif- " ferent speeds. I assure you I intend to try some " interesting experiments on this grand motion, " which, I trust, will turn out valuable. I think " I have just hit upon a plan which will prove it " mathematically correct. You will be aware that " this requires great nicety, and time.

" But to return to the carriages passing *up the* " *ascent*:—the wheels will be still gathering and " throwing off their power, as before stated, in the " descent; that is, between the rails and the ex- " treme part of the wheels, which power, you will " perceive, still assists in a forward direction.

"The weight of the carriages will now be thrown "behind that part of the periphery resting on the "rails, and the power of hauling, or propelling, will "be applied near the centre of the axles, when the "weight of the same will be raised, as if it were "with a fine tapered wedge, or screw, constantly "in motion.

"Now, I must return again to the periphery, or "prop, in contact with the rails; also, the plum-"met-line must be attached, as before, to the axles, "and watch the change of the periphery in contact "with the rails, where Nature seems to be using "every effort to run out from under the weight, yet "the carriage keeps gently rising. This regularity "of ascent will prevent the possibility of there "being time for falling bodies, in opposition, to be "called into action. The props, or parts of the "wheels in contact with the rails, are changing in "less time than can be measured by the finest chro-"nometer, yet the mind is capable of conceiving, "that stand sometimes they must. Now, according "to this reasoning, it is clear, that a portion of the "weight will be suspended in the atmosphere.

"In all revolutionary motions of this kind, the "whole of the power gained by the wheels in the "descent, will not be destroyed in ascending the "rising plane.

"I will now proceed to the top of the hill:—when "the first carriage passes over, it will move more "slowly than the rest of the train, until it has com-"pleted the greatest bend, which will be when the "centre carriage has reached the highest summit.

" At this time, the greatest strain will be applied to " bend the rails, and straighten the cord of hauling; " the wheels and axles will have made more revo- " lutions than upon a horizontal line, and the joints, " or couplings, will have rubbed a little more in " passing the segment at the bottom, and the back " of the curve at the top, &c. &c.

" After deducting the whole of the disadvantages, " it is my opinion, that there still will be a great " deal of power left in motion; and after mounting " the second summit, with the same locomotive " power still applied, the gain will be increased. " According to these laws, it will require even a " longer Railway than the Liverpool and Manchester " one, to prove the extent of its value.

" I am extremely sorry that I am at this time " so much engaged, or I would have entered more " minutely into the subject.

" Yours, very respectfully,

(Signed) " R. STEPHENSON, Sen.

" P. S.—The rails in the angles will require to be " lighter, which you can calculate yourself, with the " friction of the atmosphere.—In great haste.

" R. S."

Letter from Mr. ROBERT STEPHENSON, *Senior, to the Editor of "The London Journal of Arts and Sciences."*

[First published in 1826.]

"SIR,

"THE Specification of my Patent for "Axletrees, intended to remedy the extra friction of "carriage-wheels when passing along curves upon "Railroads, having been enrolled, and, I presume, "about to appear in your Journal, I request per- "mission to communicate to the Public, through "your medium, a few observations relative to the "inconvenience of friction which carriages now in "use labour under, when proceeding along curves "upon a line of Railway; which observation will, "I consider, shew the necessity of an invention of "the kind, and its usefulness.

"Waggons that have hitherto been used, are of "such constructions, that when passing curves in "the Railroad (if the curve be not even more than "two feet in twenty-two yards), the friction is so "great, that it requires nearly double the power "to propel the carriages that is necessary to pro- "duce the same speed on a straight line. It must "therefore be evident, that the extra power em- "ployed has the effect, merely, of grinding and "wearing away the waggon-wheels and rails; va- "rious schemes have been put in practice to pre-

" vent these inconveniences, and each has proved " ineffectual. Wheels have been used on Tram-" roads, running loose upon fixed axles, but they " have proved unsuccessful; for this reason—they " cannot be kept steady, nor can they be prevented " having play. I wish it to be understood, that " there is a great difference between the edge-rails " and Tramroads; the former being but two inches " and a quarter broad, the latter from four to five " inches. It must be known to engineers, that " wheels of a large diameter run with much less " friction than those of a small diameter. It is my " opinion, that a carriage that is to travel at the " rate of six miles an hour, ought not to have wheels " of a less diameter than three feet. If it be wished " to increase the speed of a waggon running on " Railroads, it must be evident, that increasing the " size of the wheel will do it. Suppose we take it " on an average that the wheels be four feet in dia-" meter, as the speed for carrying goods and pas-" sengers is wished to equal that of the coaches,— " the play that will soon take place in the loose " wheels, will allow them to vibrate and spread not " less than one inch and a half; and it is well known " that Railroads cannot be kept to that guage, " without sleepers or bearers, extending from rail " to rail, in order to bind the road together; and it " will also require an extra number of men to keep " the road in order.

" Carriages with loose wheels are not at all cal-" culated to rise and fall with the many irregularities " of the road they must meet with, proceeding from

" various causes, such as the blocks being sunk, by " the embankments giving way, &c. &c., as their " axletrees must be firmly fixed to the body of their " carriages. It will be doubtless the case, that, " when the carriage meets with the hollow parts in " the road, it will be resting on three wheels, and " the fourth will most probably be lifted higher than " the depth of its own flange; therefore, if the car- " riage be travelling round a curve with the hollow " inside, it must inevitably be thrown off the road.

" In consequence of these inconveniences, loose " wheels have been entirely abandoned on the edge- " rails, and those that are wedged firmly to a rota- " tory axle have been adopted, and appear to be " far superior to the loose ones. In straight lines, " the waggons now in use may suffice; but when " they meet with curves of six or eight feet to a " chain (or twenty-two yards), the friction that then " takes place is enormous.

" I can with confidence say, that the carriages " above alluded to, in passing these curves, will at " least grind off the top of the rail one-sixteenth of " an inch in twelve months. The thickness of the " top part of that kind of rails generally in use, is " only about half an inch, and those are on the " most improved principle; therefore, it cannot be " disputed when I say, that in four years the rails " in these curves will be reduced below the standard " strength required for the passing of the loaded " waggons.

" The enormous expense thus occasioned by this " extra friction, will be seriously felt by proprietors

" of Railroads; the malleable iron Railroads not " having been long enough in use to prove to the " Public the real time they will last, and the dis- " advantages before named have not been yet fully " ascertained by proprietors. The only malleable " iron Railroad that has been used for any length of " time, is that which extends from Lord Carlisle's " Colliery to Brampton, in Cumberland, about ten " miles in length, and has been made upwards of " ten years. The straight line of Railroad appears " not to be much reduced, but the smallest curve " lines have been replaced many years ago. From " these circumstances I am led to believe, that a " straight line of Railroad, where there is a great " traffic, will not last more than forty years; and " those of sharp curve lines, not more than four, " with the waggons now in use.

" These disadvantages induced me to direct my " attention to the construction of a waggon that " would obviate these difficulties; and the one I " have made will, I doubt not, overcome them.

" The wheels on my waggon are firmly wedged to " the axle, and yet will roll round the sharpest " curve without any additional friction from the " sliding of the wheels. Carriages of the ordinary " construction that travel on Railroads, having one " side more exposed to the heat of the sun than the " other, must have their wheels soon worn to a " smaller diameter, by their being exposed to a " greater heat; every practical scientific man know- " ing, that wheels exposed to the south, wear away " much sooner than those exposed to the north;

" but the two wheels being wedged upon one axle,
" as in the carriage at present used, the friction will
" be much increased, even if the carriage be moving
" on a straight line, in consequence of the wheels
" that have not been worn, travelling over a greater
" surface than the others.

" Each wheel on my carriage is so adapted, that
" it will revolve with its own axle, and every wheel
" will travel over the surface required, either in a
" straight or curved line, without any increase of
" friction, even though all of them should be of
" unequal diameter.

" There are still many disadvantages not yet
" mentioned, which Railroad carriages now in use
" labour under; for when they are lightly laden,
" and are moving at the rate of five or six miles per
" hour, and come in contact with sharp curves, they
" are generally thrown off the road; and should
" they be precipitated to the bottom of the embank-
" ments, which are in some places fifty or sixty feet
" high, the consequences might prove dreadful, and
" the expenses great, for the carriages would doubt-
" less be much injured. Suppose (which most likely
" would be the case) that there were passengers at
" that time in the waggon,—they must some of them,
" if not all, be killed upon the spot. My improved
" carriages will remove all the above-named diffi-
" culties, and passengers may travel with the greatest
" safety.

" These carriages have been tried before scientific
" men, and have answered beyond all expectation;
" they will not only move round curves with the

" same ease as on a straight line, but will travel " over the hollow parts of the Railroad that may " have sunk, in consequence of the embankments " having given way, with perfect safety.

"I am, Sir,
"Yours, &c.
"R. STEPHENSON."

THE END.

E. H. Blagdon, Printer, Bow-street, Covent-garden.

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