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Fundamental Aspects of the Unbalance Condition for the Forces involved in Rail Gun Recoil

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Abstract – The forces involved in the firing of the electromagnetic rail gun may be analyzed from Amperian, Maxwellian and Einsteinian approaches. This paper discusses these different paradigms with regard to rail gun performance modeling relating to the generation and balance of the forces caused by the currents and their induced magnetic fields. Recent experimental work on model rail guns, where the armature is held static, shows very little recoil upon the rails, thereby indicating a possible violation of Newton's Third Law of Motion. Dynamic testing to show this violation, as suggested by the authors in an earlier paper, has inherent technical difficulties. A purpose-built finite element C/C++ simulator that models that suspended rail gun firing action shows a net force acting upon the entire rail gun system. A new effect in physics, universal in scope, is thus indicated: a current circulating in an asymmetric and rigid circuit causes a net force to act upon the circuit for the duration of the current. This conclusion following from computer simulation based upon Maxwellian electrodynamics as opposed to the more modern relativistic quantum electrodynamics needs to be supported by unambiguous experimental validation.

Keywords: **recoil, rail gun, force, motion, energy, Newton, Maxwell, Einstein, Lorentz, Ampere, relativistic quantum electrodynamics**

1. Introduction

The quantification of electric current involves the estimation of force – the ampere is defined as the amount of current that flowing in two parallel conductors of infinite length and negligible width separated by one meter in free space produces a force of $2*10^{-7}$ Newton per meter of length. This force is attractive when the currents are oppositely directed, and repulsive for the other case [1].

Current is also seen as the rate of flow of electric charge: thus an ampere is also defined in terms of one coulomb per second [1]. That static electric charges attract or repel depend upon their polarities is well-known; in a state of flux – that is, as a current – such a situation will not change. Thus, the attraction or repulsion of parallel conductors carrying currents is explained. This explanation relates to the established Newtonian thinking about every action having an equal and opposite reaction, thoroughly proven in all mechanical situations including our understanding of gravitational forces. Ampere and other early researchers adopted this model to explain the forces arising from currents; in their complicated force equations [2] the magnitudes of the currents (which could be different) in the two conductors were always present, just as the masses of both bodies are present in the equation for gravitational force between them.

The situation becomes intricate for currents flowing at right angles to each other. Consider the following "hairpin" experiment conducted by Ampere in 1822 [2].

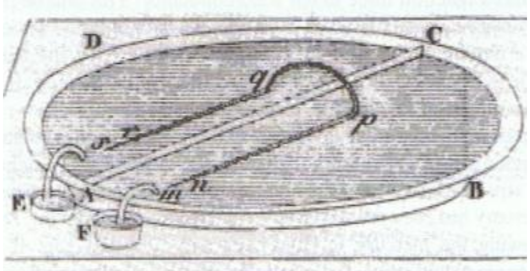

Fig. 1. Force on a current-carrying metal "hairpin" floating on mercury. The above diagram has been obtained from the book "Newtonian Electrodynamics" by P Graneau and N Graneau [2].

Ampere's own drawing of his experiment is shown in

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Fig. 1. A metal “hairpin” (shown as the dark lines as *npqr*) bridges (via the segment *qp*) the insulating ridge partitioning a bowl filled with electrically conducting mercury, upon which the metal hairpin floats. When current is passed across the points p and q via the metallic arms *np* and *rq* with application of a potential difference across E and F and the presence of the conducting mercury in between, it is observed that the “hairpin” accelerates towards point C. Thus, a net linear force in the direction of the metallic arms acts upon the hairpin. Till this experiment, it had been known that currents in parallel conductors either repel or attract, depending upon the current directions.

Interestingly, this effect can be explained in three different ways. Ampere saw it as equal and opposite forces corresponding to the current elements in pq and the arms qr, pn causing the net transverse force on the “hairpin”, which should be balanced by the force travelling down the arms to the mercury causing pressure, and ultimately to the edge of the bowl around E and F. The later Maxwellian approach would explain it as the result of the interaction of the induced magnetic field in pq resulting from the currents in the arms, and the current in pq. This is the standard electrical engineering approach. The modern Einsteinian approach, developed by Einstein to overcome what he considered were limitations in the Maxwellian approach, negates the existence of ether and consequently the actual existence of electrical and magnetic fields. Relativistic quantum electrodynamics would have the electrical energy in the circuit moving much as particles with momenta; the arm pq thus being a barrier to these particles would experience a force.

As it is improbable that a physical phenomenon can be described correctly with three widely different and extremely fundamental paradigms, a major thrust of this paper is to determine which of the three paradigms is most suited to explain the effect described in Fig. 1.

The electromagnetic rail gun is a practical device which relates to the “hairpin” effect, in that a force transverse to that repelling the rails (the arms of the “hairpin”) is unleashed with the application of high current. The importance, dynamics and modeling of the rail gun with respect to the recoil involved will be discussed in the later sections.

2. Rail gun recoil analysis: Amperian, Maxwellian and Einsteinian approaches

Rail guns are an important technology for the future as they have many inherent operational advantages. There is no need for bulky and dangerous explosives with finite shelf life; they produce very high bullet velocities; they derive their energy from standard energy systems often found on large equipment such as ships and tanks. We may expect a range of potential commercial applications (notably in space, mining and civil engineering) that could take advantage of the new rail gun technology, with suitable modifications and adaptations. These issues have been dealt by the authors in a recent conference publication [4].

A rail gun has two parallel conducting rails (represented by AD and BC in Figure 2 below) with specially designed lengths and cross-sectional geometry. A large current (generated by a powerful source like a battery as shown in Figure 2 or in practical circuits a bank of capacitors) is passed through these rails via a sliding short circuit component (represented by CD) across the rails. This is the armature (the projectile or bullet) that accelerates very fast by the forces formed due to the induced magnetic field caused by huge currents flowing through the arms and the same current flowing through it; the force acting upon the projectile is thus proportional to the square of the current. The above explanation derives from Maxwellian electrodynamics.

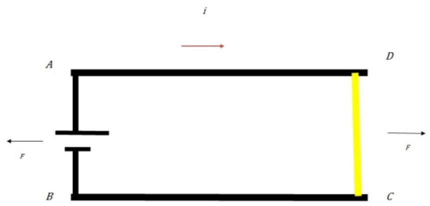

Fig.2. Basic geometry of an excited rail gun in two dimensions [3]

Following the thorough experimental work done by Schroeder [5] which was followed up by Putnam [6], we learn that only around 1% of the predicted mechanical reaction is directed oppositely to the action force on the static armature in the pendulum-suspended model rail gun. However, it seems premature to claim that Newtonian laws of motion have been violated in this instance. The static tests were concerned simply with current in the rails and the armature; the conducting leads that carry the same current as the rails, along with the battery power source, that together with the rails and armature form the total current loop, have not been included in the experiment to find the location of the ultimate reaction. The reaction from the force on the armature could be present in the connection leads and the battery, so from the overall system point of view the proposed invalidity of the Newtonian laws of motion is debatable. [4]

In Fig. 3 we observe that with the Amperian approach, an axial component of the reaction force must be present. The current flowing along the perpendicular rail and armature segments (shown by bold arrows as current segments) must create balanced forces from the third Newtonian law of motion (shown as solid arrows, inclined to the direction of the current). These forces are decomposed into force components parallel and perpendicular to the current segments, as shown by the dotted-line arrows.

Putnam in his model rail gun experiment [6] caused a physical break in the rails of the model rail gun wholly suspended as a pendulum. That break was filled with conductive liquid. If the Amperian model was valid, then there would be an axial component of force along the rails, and the effect of same would become visible with the rail end pressing against the fluid. However, this was not apparent – there was very little (1%) axial component of reaction force.

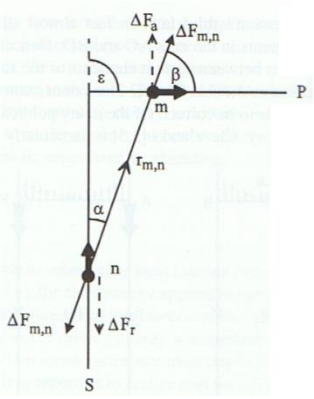

Fig. 3. The equal and opposite forces involved in the Amperian model of the rail gun. The above diagram has been obtained from the book "Newtonian Electrodynamics"by P Graneau and N Graneau [2].

While Newtonian laws may yet be preserved, the Putnam experiment clearly shows that the Amperian electrodynamics paradigm does not model rail gun behaviour validly; one may conclude that the Amperian equations linking forces with currents thus lack generality.

We next consider Einsteinian electrodynamics: In his famous paper titled "On the electrodynamics of moving bodies" [7] published in 1905 Einstein starts off with this statement expressing his dissatisfaction with Maxwellian *electrodynamics "It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena."* Indeed the Lorentz relation based upon Maxwellian electrodynamics (Equation 1) is inherently disturbing as it does not propose any reaction force caused by the initiating current as the Amperian equations do; this opens the scope for violation of the inertial condition, so sacred and vital in physics. Einstein goes on to propose an entirely different and radical world view, where electromagnetic fields have no existence as the medium for their propagation, namely aether. *"The introduction of a "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolutely stationary space" provided with special properties, nor assign a velocity-vector to a point of the empty space in which electromagnetic processes take place"*

The absence of aether raises the issue of the new manner of energy transfer via electric current. The Poynting vector [8] indicating energy flow involving electric and magnetic fields travelling in free space at the speed of light is based upon field theory - a Maxwellian construct using aether as the medium for the transmission of energy using wave motion. It is now no longer applicable in modern physics. Quantum theory proposes that energy travels through free space as tiny packets or quanta [9]. Thus instead of a energy travelling in fixed aether as wave motion, we have particles of energy rushing along in a continuously distorted space and time frame; effectively much like the flow of air or water compressed in a pipe. To modern physicists, Einstein's relativistic space distortion resulting from the invariance of light speed, along with energy now being seen as composed of minute particles, explain the natural phenomenon more satisfyingly then the Lorentz relation which is based upon Maxwellian electrodynamics. Despite its practical use in all electrical engineering matters, Maxwellian electrodynamics is dismissed by Richard Feynman in the final words of his Nobel Prize acceptance speech [10]: "*So what happened to the old theory that I fell in love with as a youth? Well, I would say it's become an old lady, that has very little attractive left in her and the young today will not have their hearts pound anymore when they look at her. But, we can say the best we can for any old woman, that she has been a very good mother and she has given birth to some very good children. And, I thank the Swedish Academy of Sciences for complimenting one of them."*

Within the scope of modern physics including Einsteinian electrodynamics, the inertial condition is always present as a supremely necessary and always given condition – all forces in any closed system therefore must be balanced. The motion on the element designated *pq* in Fig. 1. occurs because of the arrested momenta of the quantum energy particles or quanta that possess mass as a result of their energy; on return to the source these particles will exert exactly the same force in some way or the other involving space-time distortion. Also, this approach predicts no axial force along the rails or arms of the “hairpin”, so the Schroder and Putnam experimental results [5], [6] are reconciled with Einsteinian electrodynamics.

With Maxwellian electrodynamics, we can also adequately explain the results of Ampere’s “hairpin” experiment and the Schroeder-Putnam experiments, in terms of electromagnetic fields and currents. The axial component of force in the arms of the “hairpin” or the rails have to be non-existent under this paradigm, for the intraction of the magnetic field arising from the armature current and the current in the rail will cause a purely outward force.

The correct explanation for rail gun behaviour is now a toss-up between the aged Maxwellian electrodynamics and the new Einsteinian electrodynamics. If it can be proved with experiment that there is no force unbalance to the closed rail gun circuit suspended in free space, then the Einsteinian electrodynamics paradigm will be fully vindicated if Maxwellian electrodynamics predicts an unbalanced force condition, where the action is not balanced by reaction, and thus, a net force acts upon the system containing the current for its duration.

In their earlier paper [4], the authors had proposed such an experiment. Excerpts from that published work are shown in the next section.

3. Proposed Dynamic Rail gun model

Consider the experimental situation in Figure 4. As opposed to the design in Figure 2, simple geometric manipulations to the rail gun circuit configuration has been made, mainly related to the leads, by curving them as shown in the diagram, which is now three dimensional [4]. Assume the above experimental set-up exists in far outer space, thus there are no retarding forces as friction, gravity or air resistance. There is effectively a static laboratory reference. The battery is secured on a flat plate. Two long conducting rails (bus bars, for instance) also fixed to the plate and are connected in parallel directly to the positive and negative terminals. The armature (an electric short of some mass) is dropped across and upon the rails, using a feeding system not shown in the diagram. A heavy current is drawn from the battery, which passes through the short. The magnetic fields in the rails impact on the charges in the armature, giving it the Lorentz and Ampere forces to propel it across the rails and out of the gun. Following the law of conservation of momentum, the battery-gun-plate system should experience a force that would make it move in the opposite direction of the armature. If there is such acceleration from recoil that would give it a finite velocity, the battery-gun-plate system would have to move as per rocket action. On the other hand, if there is no recoil force, the battery-gun-plate system would not move; or rather, move only as per the much lower recoil indicated by the Schroeder-Putnam experiments. A value of around *0.4N* was observed as the static force acting on the armature in those experiments when the current was *1200A.* This should be a reasonable value, for conclusive observation of the recoil on the entire closed system. Using the heuristic value of $F = 0.4\ N$, if the set-up has armature mass $m = 1\ Kg$ with total system mass $M = 40\ Kg$, and the rail gun has *length* $s = 1\ m$, then assuming no friction at the rails the exit speed v of the armature starting from rest will be *89 cm/s*, and the recoil velocity V for the total system will be *2.2 cm/s*. The calculations are done below [4].

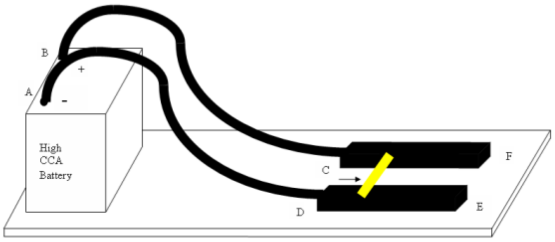

Fig. 4. Experimental set-up to determine the validity of Newtonian laws through measurement of rail gun recoil in a closed system [4]

From constant acceleration a over the length of the rail gun, we have $a = F/m = 0.4\ m/s/s$ and $v = sqrt(2as) = 0.89\ m/s$. Using the conservation of momentum principle the recoil velocity V of the set-up should be $V = vm/M = 2.2\ cm/s$ [4].

The extreme simplicity of this proposed experimental design may be noted. We have done away with cables, switches, resistors, meters, and other complex equipment present in the Schroeder setup. To maximize the current in the loop so as to exert the greatest force upon the armature, we reduce the resistance to as low a value as possible by shortening and thickening the electrical lengths, and decreasing the resistance at the sliding or rolling contacts at the rail-armature junctions [4].

In the terrestrial laboratory, we may suspend the whole system as a pendulum; or float it on a liquid; or have ball bearings between the plate and a hard surface to minimize friction. In this paper, we discuss the first approach, as it should give the most conclusive results [4].

A pendulum based system will be adequately sensitive at low currents and for short lengths. For example, in the configuration detailed above (using the recoil velocity $V = 2.2\ cm/s$ for a *40 Kg* mass) the height H moved up by the suspended system will be *0.0246 mm* using energy conservations principles where the loss of kinetic energy will be taken up by the gain in potential energy. Thus, $0.5MV^2$, which is the loss in kinetic energy when the bob will rise to its highest position will be equal to *MgH*, the resulting gain in potential energy. Whence, $H = 0.5\ V^2/g = 0.0246\ mm$, where g is the acceleration due to Earth's gravity [4].

For a *2 m* long pendulum which has the rail-gun system as the pendulum bob, that height *H* would amount to a lateral displacement of *9.92 mm*, or a swing of *0.28 degrees*. With optical distance measuring techniques, this lateral displacement could be accurately measured even in the environment of large changing electric and flux fields. To measure the magnitude of the postulated low recoil for the rail gun, this seems an ideal method. Magnetic damping will be used to steady the platform before firing the armature [4].

Modern Lithium-Ion batteries are capable of providing a much higher current that the Lead-Acid batteries used in the Schroder experiments. Such batteries are also much lighter. Typically, we may get *2200A* current with a *3.5 Kg* battery. While these batteries are expensive, they would provide the pendulum swings of much greater magnitude than discussed above and provide easy visual confirmation of recoil or non-recoil [4].

3.1 Technical Difficulties

Unfortunately, severe technical difficulties have been encountered in the practical realization of the abovementioned experiment. The main issue related to the arresting of the armature by the rails due to the welding action caused by arcing resulting from the high current transfer between the rails and the armature . It is hoped that this problem will be removed with more involved and accurate mechanical engineering. Alternative experimental strategies are now being pursued.

4. Computer Simulation

A software 3D simulation tool using the Rapid Application Development C++Builder 6 development platform running on Windows has been specially created to model the rail gun configurations presented in this paper.

In the context of this paper it is important to know that this tool employs the most basic and well-used formulas based upon Maxwellian electrodynamics. These equations have been dealt with in detail by the authors in [4]. For the sake of completion, they are repeated below.

The Lorentz equation for finding the force upon a charged mass in an electromagnetic field, given by:

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \qquad (1)$$

Here, **F** is the Lorentz force on the conductor in newtons, q is the coulomb charge in the conductor, **E** is the electric field as volts per meter, and **v** × **B** is the vector cross product of the charged particles' average velocity in meters per second in the conductor with the local magnetic field expressed in teslas [4].

To calculate the Lorentz force upon any current segment, we have to know the magnetic field acting upon that current segment. The magnetic field at any point P arising from a current segment is found from the empirical Biot-Savart law, namely

$$d\mathbf{B} = \boldsymbol{\mu}_0 * I * d\mathbf{l} \times \mathbf{r}/(4\pi R^2) \qquad (2)$$

where d**B** the magnetic induction field at point P due to the current segment formed by the current I over the incremental length d**l**; $\boldsymbol{\mu}_0$ is the magnetic permeability and a constant value; **r** is a unit vector pointing in the direction of the line joining vector element d**l** (positive in the direction of current) to point P; R being the distance of P from the current element. Equations (1) and (2) are vector equations; × is the cross product operator [4].

The magnetic field at any incremental current element can be found out by the vector summing up of the incremental magnetic fields from all the incremental current elements in the rail gun circuit. This process can be repeated for all the current elements in the loop. After knowing the magnetic fields thus, the Lorentz equation can be used to find the incremental force acting at every incremental current element, using the derivative equation below [4].

$$d\mathbf{F} = i * d\mathbf{l} \times \mathbf{B} \qquad (3)$$

The above equations (1-3) have been derived in [1].

Thus, the force on the armature, the rails, the conducting leads and also the current in the battery can be calculated on an indicative basis when the circuit geometry is approximated by lines. More rigorous methods will use volumes. However, to get some notion as to the inertial condition, that is, to learn whether or not a current in a circuit causes a net force upon the circuit, we submit that approximating a circuit with just lines is indicative though not final; for as we start using volumes the forces calculated upon the circuit elements will decrease. Only actual and physical experimentation can settle this issue with finality.

4.1 Results from Computer Simulation of Rail Gun geometries

The first version of this tool verifies the stated position of Su et al [11]. Thus detailed finite element analysis verifies that in an idealised circuit of rectangular configuration, as in Figure 2, the electro-dynamic force upon the armature is balanced by the reaction at the battery end. Thus, Newton's Third law of motion is preserved, considering the entire system.

Our software tool predicts that when there is asymmetry in the circuit (as is the case in Fig. 4) there will be a net force acting upon the circuit, the magnitude of which varies as the square of the current.

The circuit configuration for Fig. 4 has been modeled and simulated. Intuitively we may consider that this numerical result is only logical, given the correctness of the software implementation. As the electrical connections to the battery terminals are roughly oriented at right angles to the parallel rails, as per Figure 4, and the power connections to the rails from the battery do not possess sharp angles, the magnetic field from those connections impacting upon the battery current will now be at right angles to the magnetic field acting upon the current in the armature. The forces from the current in the battery will thus be forced up, or down – and not opposite to the armature motion. The Lorentz forces at the load and power ends will thus be orthogonal. In which case, one may expect the lack of opposite action, or recoil for the whole closed system, provided that the recoil is not absorbed by the leads. Fig. 5 shows how rapidly the force along the edges of the armature increase with the applied current and also remain significant over the entire length. This is in contrast to the situation at the other end, where there are shallow curves that do not permit such such increases in force caused by the right-angle junctioning.

Characteristics of this simulation program (named *Inertia Blaster* by its author Arindam Banerjee) are: it models arcs in the principal planes and straight lines in 3D; for the greatest computational accuracy, specially over the sharply rising curve regions that is those with centre-subtended angles nearing 90 deg, it is ensured by appropriate coding that all the finite element lengths remain the same over the regions, irrespective of slope. This is done by avoiding the use of parametric functions, normally used to find the co-ordinates of curves. The outcome of this precaution is that the output results are found to remain reasonably constant over a range of finite element sizes. Such superior quality of output provides increased assurance about the validity of the finding that finite element simulation does provide the insight that a current in a freely held asymmetric and rigid circuit causes a net force to act upon the circuit.

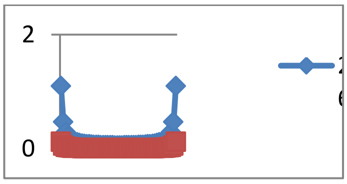

Fig. 5. Force (in Newtons) acting upon the finite elements along the 50mm armature length of a rail gun simulation result.

A geometry file is created and run with other input variables such as finite element size and current magnitude. The output from the simulation shows the magnetic fields and forces acting upon every finite element, along the three dimensions. The forces acting upon the individual finite elements are summed to find the total force acting upon each circuit element, and finally the entire circuit.

For the rail gun configuration in Fig. 4, the following geometry file is created. The curvy leads to the rails are expressed both as 3D lines and arcs in the principal X-Z plane. In the Line/Arc column information about the principal planes and the convexity or concavity of the arc is given.

Table 1. Geometry input file for *Inertia Blaster*

X_start	Y_start	Z_start	X_end	Y_end	Z_end
0	0	0	0	300	0
0	300	0	0	300	500
0	300	500	600	300	500
600	300	500	1000	175	0
1000	175	0	1500	175	0
1500	175	0	1500	125	0
1500	125	0	1000	125	0
1000	125	0	600	0	500
600	0	500	0	0	500
0	0	500	0	0	0

….the contiguous columns are continued below

Line/Arc	X_c	Y_c	Z_c	del
0	0	0	0	#
0	0	0	0	#
134	300	300	500	#
0	0	0	0	#
0	0	0	0	#
0	0	0	0	#
0	0	0	0	#
0	0	0	0	#
134	300	0	500	#
0	0	0	0	*

The impact of finite element size with respect to the net force (in Newtons) obtained upon the circuit is presented in the following table. The current is 2000 Amperes.

Table 2. Variation of net force upon circuit with FEM size

FEM (microns)	Force_X (N)	Force_Y (N)	Force_Z (N)
50	4.25E-01	3.42E-04	-6.87E-01
100	4.31E-01	1.86E-05	-6.88E-01
500	4.21E-01	8.80E-07	-6.87E-01
1000	4.21E-01	1.93E-06	-6.87E-01
2000	4.22E-01	2.94E-06	-6.87E-01

5. Conclusion

The extraordinary assertion that current in a rigid and asymmetric circuit causes a net force to act upon it is a novel claim; for universal acceptance it has to be supported by experimental evidence and receive widespread peer approval. It may just be that so far the world has not noticed the very small amount of net force on a circuit that may be generated with normal currents. Using our theoretical understandings we are now close to completing experiments designed to produce the required experimental evidence. If this effect indeed exists and can be amplified with new technology, in due course its impact should be substantial. Advances could be made in the fields of motion and energy generation with the development of entirely new classes of electrical systems.

At another level, with the availability of unambiguous experimental evidence relating to the existence or non-existence of the new effect discussed, our theoretical understanding of the basic nature of energy propagation throughout the universe will be solidified; the existence or non-existence of aether will confirm the validity of Maxwellian electrodynamics or Einsteinian electrodynamics and thereby provide a sharper and correct picture of certain important aspects about the workings of Nature.

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