Journal of Space Mixing, 6 (2016) 1-17

The Manz Effect Provides a Table-Top Demonstration of Attraction Between Electrostatic Charges of the Same Sign

Thomas A. Manz, Department of Chemical & Materials Engineering, New Mexico State University, Las Cruces, NM 88003-8001, email: tmanz@nmsu.edu

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Abstract:

An unusual electronic phase transition was observed in a pair of parallel thin metallized dielectric films. When charged with excess electrons and then grounded, an electronic phase transition occurred during the discharge step that led to a strong attraction between the paired metallized films. This phase transition effectively liquefied the charge carriers. (The effect could also be produced using a deficiency of electrons to create net positive charges.) The resulting electronic phase (and its attractive force) persisted for several days with no apparent decay at ambient temperatures (around 25 C). This electronic phase exhibited free current lifetimes lasting seconds before decay. Specifically, after rotating the films along an axis not parallel to the films, the magnetic field due to rotational motion of the charge carriers relative to the thin films persisted for seconds before dissipation. Extensive experimental and theoretical analysis revealed the attraction between these plates persists even though the static charges on the two plates have like signs. A series of videos and pictures document the effect's reproducibility. This appears to be the first report of electrostatic attraction between macroscopic distributions of same signed static charge carriers. After extensive investigation, the underlying reason for attraction of like charges was found to be scattering of electromagnetic oscillations off the electrostatic potential kink associated with each confined charge layer. Preliminary calculations and experiments showed this scattering should be most prominent within the infrared and microwave regions. This suggests devices incorporating the effect should find applications for shielding electronic circuits and other objects from electromagnetic oscillations in the infrared and microwave regions.

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keywords: electrostatics, electrostatic charge, electrostatic forces, physics, experiments, electromagnetic scattering, electromagnetic waves

1. Introduction

Our understanding of the natural world around us is facilitated by practicing the scientific method. In the scientific method, hypotheses and theories are put forth and experimentally tested. Sometimes experiments produce completely unexpected results that challenge the status quo. In these cases, new theories must be proposed and tested to figure out what is going on. This was the situation I found myself in as an undergraduate student performing experiments with static electricity more than twenty years ago. The physics textbooks said static charges of like sign repel each other, but when I performed experiments an opposite result emerged. I was stunned and puzzled. On the one hand, the textbooks seemed well thought out and based on centuries of experience. On the other hand, the experimental apparatus before me was not following the textbooks. So began a quest to figure out what is going on. I hypothesized everything I could think of. Then I carefully evaluated each of these hypotheses to eliminate the ones that were not valid.

This article describes experiments showing electrostatic charges of like signs can attract each other over macroscopic distances (e.g., charged plates placed ~1 cm apart). A variety of potential explanations are ruled out. Finally, I show this effect is due to scattering electromagnetic waves off the electrostatic potential kinks that occur at the locations of each confined charge layer. This electromagnetic scattering causes a force that pushes the two plates together. In this article, videos and pictures document the effect and its reproducibility. I hope this effect fascinates you.

2. Experimental Results

2.1 Electronic Phase Transition

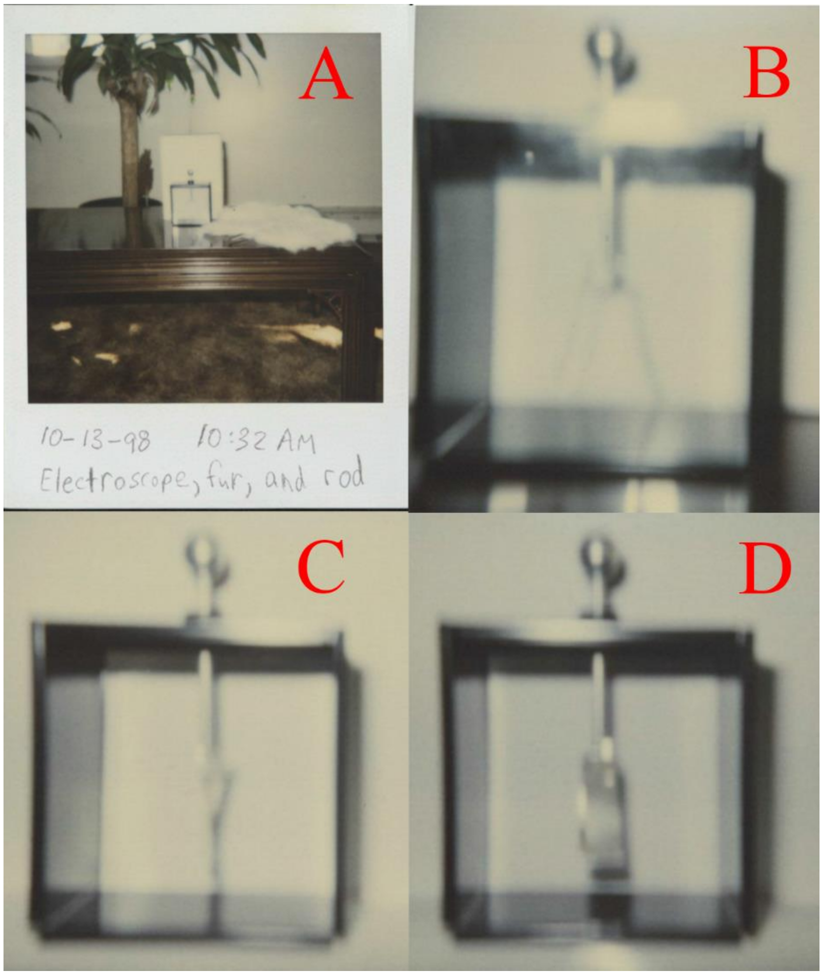


Figure 1: Reproductions of Polaroid photos taken by the author on 13 October 1998. *Panel A*: Electroscope, rabbit fur, and plastic rod (believed to be acrylic) sitting on a table in the author's apartment. *Panel B*: Electroscope as charged with the plastic rod showing the electroscope leaves deflected apart. *Panel C*: Electronic phase formed when the electroscope was grounded. The metallized foils were strongly attracted to each other. *Panel D*: The electroscope leaves have been rotated 90 ° to show the aluminum and gold sides. The aluminum side of the front leaf is slightly to the right of the gold side of the rear leaf.

In the early 1990's while performing experiments with static electricity, I discovered an unusual effect that cannot be explained by classic electrostatic theory. I repeated these experiments and took Polaroid photographs in 1998. Some of these photographs are reproduced in Figure 1. Figure 1(A) shows an electroscope, rabbit fur, and plastic rod. Rubbing the plastic rod against the rabbit fur causes it to acquire a static electric charge. The electroscope consists of a metal case that holds glass windows in front and back. An electrical insulator separates the electroscope terminal from the metal case. The electroscope terminal consists of a metal ball attached to one end of a metal rod with a small metal hanger attached to the other end of the metal rod. The two electroscope leaves hung from the small metal hanger. Touching the charged plastic rod to the electroscope terminal caused the leaves to acquire a static charge. This static charge caused the leaves to repel each other and deflect apart, as shown in Figure 1(B). Grounding the electroscope terminal caused the leaves to move towards each other. Classic electrostatic theory predicts the two grounded leaves should discharge and freely dangle parallel to each other with a space of air between them. In contrast to the behavior expected from classic electrostatic theory, the leaves instead exhibited an abrupt transition from repulsive to attractive force leading to a strongly attractive bound state between the two leaves, as shown in Figure 1(C). Figure 1(D) shows a view of this attractive bound state in which the electroscope terminal and leaves have been rotated 90 °.

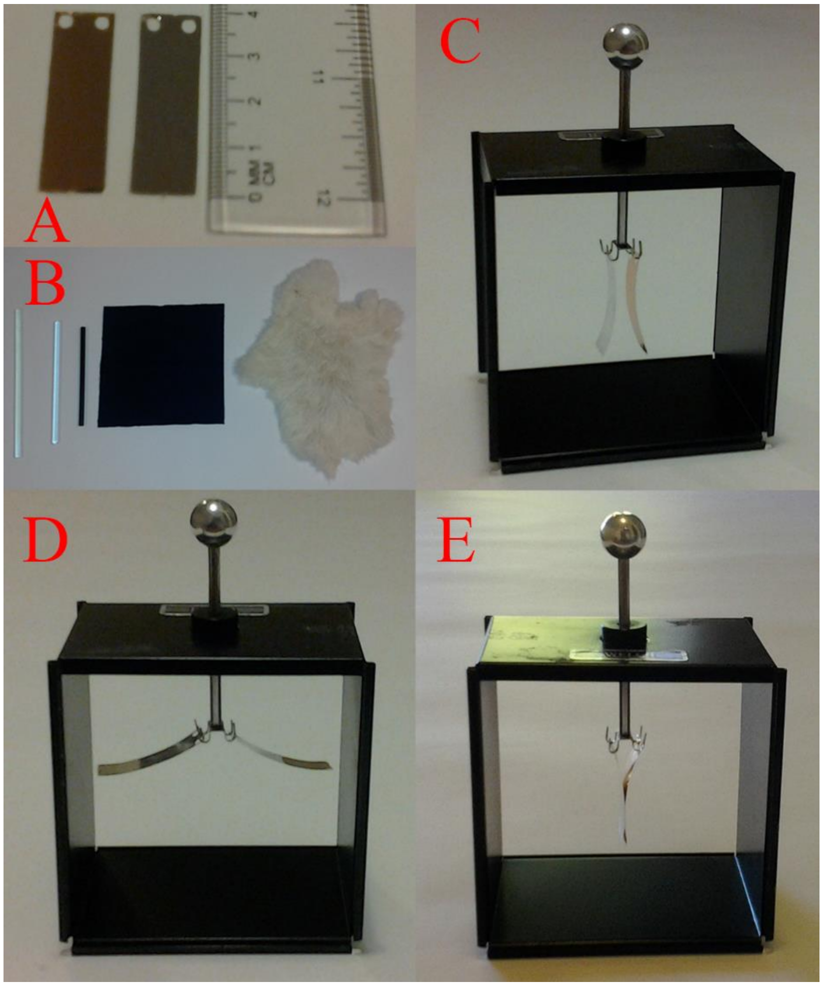


Figure 2: Producing the attractive bound state. *Panel A*: Metallized foils showing gold side (left leaf) and aluminum side (right leaf) beside a ruler showing leaves are 13×40 mm in size. *Panel B* (left to right): Example materials used to produce static electric charges: plastic rod (believed to be acrylic), lucite rod, ebonite rod, wool cloth, rabbit fur. The plastic rod on the far left and the rabbit fur on the far right are the same as pictured in Fig. 1A. *Panel C*: Electroscope with leaves in uncharged state. The gold sides are facing together and the aluminum sides are facing apart. *Panel D*: Electroscope with leaves in highly charged repulsive state. This state is produced from the state in Panel C by touching a highly charged rod to the electroscope terminal. *Panel E*: Electroscope with leaves in attractive bound state. This state is produced from the state in Panel D by grounding the electroscope terminal.

Recent high-resolution photographs and videos taken with my cell phone camera are shown in Figure 2 and Video 1. The electroscope leaves consisted of a thin dielectric (plastic) layer, a thin aluminum layer, a thin gold layer, and another thin dielectric (plastic) layer. (As described in Section 2.5, leaves in the early 1990's experiments had only one dielectric layer with the gold layer exposed to air.) As shown in Figure 2(A), each leaf measured 13 mm × 40 mm. Figure 2(B) shows examples of materials used to produce static electric charges. In addition to those materials shown, I also used a glass rod and tested silk and cotton cloths for charging the rods. My tests showed the easiest way to produce a negative static charge was by rubbing the plastic (acrylic or lucite) rod on the rabbit fur to charge the rod negatively. All of the photographs and videos in this paper were produced by charging the leaves negatively using the negatively charged plastic rod. My tests showed the easiest way to produce a positive static charge was by rubbing the glass rod on the wool cloth to charge the rod positively. The tests for positive charging are described in Section 2.5. The electroscope charging and discharging sequence is shown in Figure 2 (C, D, and E). First, the electroscope is uncharged with the two leaves dangling freely, as shown in Figure 2(C). After the charged plastic rod was touched to the electroscope terminal, the leaves acquire a static charge and repel each other, as shown in Figure 2(D). Grounding the electroscope produces the attractive bound state, as shown in Figure 2(E). Video 1 records in real time this charging and discharging sequence to produce the electronic phase transition.

Video 1: A video showing charging and discharging the paired metallized foils to produce the phase transition from repulsive electronic phase to attractive electronic phase. *Sequence*: This video begins with two uncharged leaves hanging freely. Then, a charged plastic rod is contacted to the electroscope terminal to add net charge to the leaves causing them to repel. Then, the electroscope terminal is grounded to cause the two leaves to undergo an electronic phase transition that produces an attractive bound state. Similar experiments were captured in each video to demonstrate experimental reproducibility: **Video 1a (left, 7.4 seconds)** and **Video 1b (right, 2.6 seconds)**. Click each video to play.

2.2 Electronic Phase Stability

Several experiments were performed to demonstrate the electronic phase is stable. When an electroscope with the paired metallized dielectric foils in the negatively charged attractive bound state was left undisturbed for days, no appreciable change was observed. Passing an object, such as a pencil or finger, completely through the leaves from top to bottom showed the leaves were not stuck together through a friction or atmospheric pressure force. (In the 1990-1994 experiments, I even completely pulled the two leaves apart so that no portions of them were in direct contact and the attractive force remained unabated so long as the middle portions of the leaves were closer than their tops. (In this article, the terms "middle", "top", and "bottom" of a leaf refer to different positions along the leaf's long dimension.) The attractive phase always settled to the portions of the leaves closest together. The leaves could be touched anywhere on their inner dielectric surfaces, but only on the outer surfaces where the leaves were farther apart (e.g., top or bottom sections). Touching the outer metal surface where the leaves were close together (e.g., middle section) would immediately destroy the attractive phase there. Amazingly, an even larger excess negative charge could be added to the two leaves to produce attraction in one portion of the leaves and repulsion in another portion of the leaves. Apparently, the added negative charge migrated to the portions of leaves farther apart leaving the attractive phase undisturbed. As shown in Figure 3 and Video 2, grounding the electroscope terminal removes this excess repulsive charge leaving the attractive phase undisturbed on the leaves. This proves the bound state cannot be due to one positively charged leaf attracting a negatively charged leaf, because the attractive leaves carry the same sign of net charges. The attraction of two leaves having the same sign of net charges proves this attractive force involves more than classic electrostatic interactions.

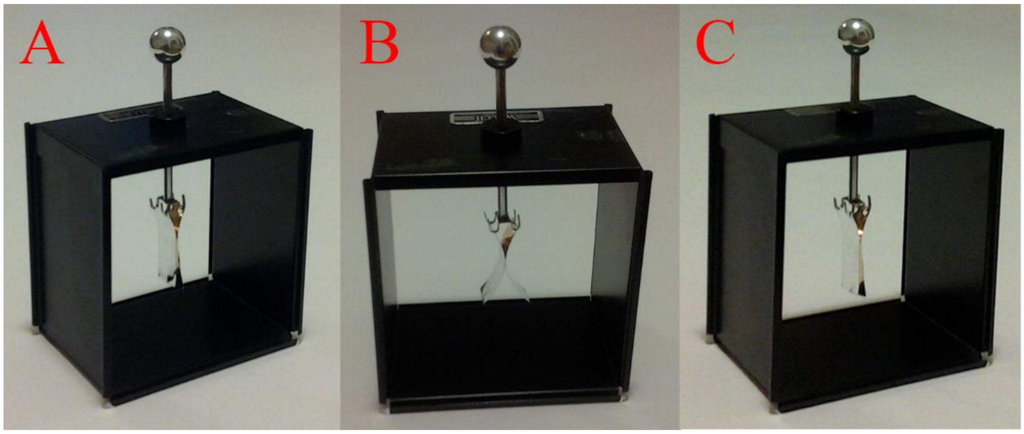


Figure 3: Starting with the paired metallized dielectric foils in the attractive bound state (panel A), touching a charged plastic rod to the electroscope terminal added more static electric charge causing the leaf pair to repel each other at the bottom while retaining the attractive bound state in their mid-section (panel B). Grounding the electroscope terminal removed this repulsive interaction and returned the leaves to their fully attractive bound state (panel C). This experiment proves the attractive bound state is not due to a positively net charged leaf attracting a negatively net charged leaf. Therefore, the attractive bound state must be due to one or more physical interactions besides classic electrostatic interactions.

Video 2: A video demonstrating stability of the bound state even when additional charge is added to the metallized foils. This proves the bound state cannot be due to one positively charged leaf attracting a negatively charged leaf, because the attractive leaves carry the same sign of net charges. The attraction of two leaves having the same sign of net charges proves this attractive force involves more than classic electrostatic interactions. *Sequence*: This video begins with the two leaves in the attractive bound state. Then, a charged plastic rod is contacted to the electroscope terminal to add additional net charge to the leaves causing them to repel at the bottom while still being attracted at the center. Finally, the electroscope is grounded to remove the repulsive interaction at the bottom of the leaves. Similar experiments were captured in each video to demonstrate experimental reproducibility: **Video 2a (left, 9.3 seconds)** and **Video 2b (right, 7.3 seconds)**. Click each video to play.

2.3 Induced Magnetic Moments and Free Current Lifetime

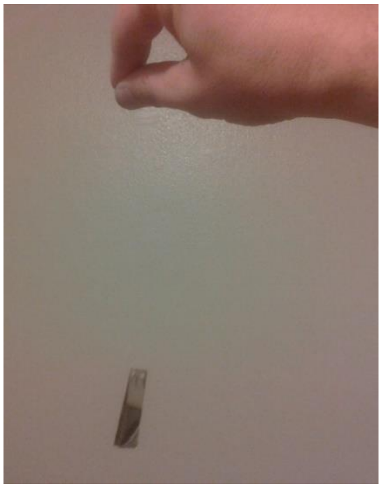
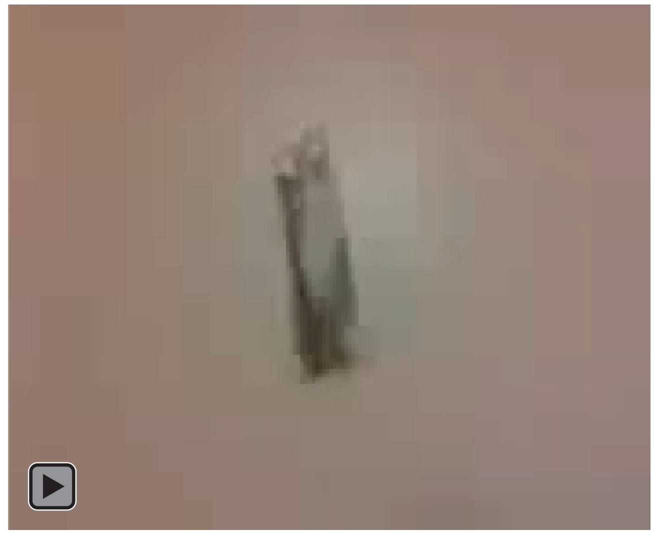


Figure 4: The pair of metallized foils was suspended by a polymer thread that was looped through the holes in the leaves and tied into a knot. This thread is so thin that it is not visible in the picture. The leaves were suspended in the Earth's gravitational field by holding the top end of the thread in my hand to form a pendulum. The distance between this pendulum and the white wall behind it was several feet. This configuration allowed experiments to be performed that studied rotation of the suspended leaves to produce induced magnetic moments that interacted with the Earth's magnetic field as shown in Videos 3a and 3b.

Video 3: A video demonstrating a small magnetic moment induced by rotating the paired charged metallized foils in the attractive bound state. The pair of metallized foils was suspended by a polymer thread that was looped through the holes in the leaves and tied into a knot. This thread is so thin that it is not visible in the videos. The leaves were suspended in the Earth's gravitational field by holding the top end of the thread in my hand to form a pendulum. The distance between this pendulum and the white wall behind it was several feet, so interaction between the pendulum and the wall was negligible. The North-South direction was parallel to the wall. The direction of Earth's North Magnetic Pole was to the right, and the direction of Earth's South Magnetic Pole was to the left. *Sequence*: By twisting the top end of the thread between my thumb and index finger, a torque produced on the thread was transferred down to the leaves to set them into rotation. A temporary magnetic moment was induced in the leaves upon rotation. This induced magnetic moment caused the leaves to behave as a temporary compass. Specifically, the small induced magnetic moment caused the leaves to temporarily take a break from rotating and align the induced magnetic moment along the North-South direction, such that the plane of the leaves was roughly perpendicular to the wall. When rotation ceased, the induced magnetic moment would decay in magnitude due to collisions between the charge carriers and each other, the walls of the leaves, and/or defects in the leaves. Once the magnetic moment had decayed sufficiently, the leaves resumed rotation due to the torque applied by the thread. This rotation would build up the induced magnetic moment again. Once the induced magnetic moment had been restored to sufficient magnitude, the interaction between the induced magnetic moment and Earth's magnetic field would overpower the thread torque, causing the leaves to once again pause from rotating and behave as a temporary compass with alignment due to Earth's magnetic field. This sequence could be repeated. Similar experiments were captured in each video to demonstrate experimental reproducibility: **Video 3a (left, 39.4 seconds)** and **Video 3b (right, 19.2 seconds)**. Click each video to play.

Experiments were performed to characterize free currents produced by rotating the leaves along an axis not parallel to the leaves. (When the leaves suspended from the thread were rotated, the centrifugal force tilted the leaves outward thus causing the plane of the leaves to align along a direction intermediate between perpendicular and parallel to the rotation axis.) When the leaves are rotated, the charge carriers will not begin to rotate until they experience collisions. In this case, rotation of the charge carriers occurs by circular electric currents induced within the leaves. This is analogous to rotating a bucket of water in which the water rotates together with the bucket only after sufficient time has elapsed. If rotation of the bucket is ceased, the water will continue to rotate for a short time until its rotational energy has dissipated through collisions. The charged leaves exhibited a similar effect in which the net charge carriers are analogous to the water in the bucket and the leaves are analogous to the bucket. Since an electric current loop produces a magnetic moment, the rotational currents of the net charge carriers can be monitored by observing the interaction between the leaves' magnetic moment and Earth's magnetic field. To perform these experiments, the leaves were suspended by a fine thread that allowed them to rotate (Figure 4). The leaves acted as a temporary compass with their temporary magnetic moment aligning along Earth's magnetic field, as shown in Video 3.

The early experiments (1990-1994), using the pair of plastic foils coated with gold on one side, produced a stronger attractive force between the two leaves and exhibited longer free current lifetimes. Rotating the (1990-1994) leaves produced much stronger alignment with Earth's magnetic field than that demonstrated in Video 3 using the later leaves. The earlier leaves exhibited strong compass-like alignment that lasted for several seconds. This indicates the (1990-1994) leaves had a free current lifetime of several seconds.

2.4 Thermal Disruption Effects

My index finger felt distinctly cooler when placed between the (1990-1994) charged plates in the attractive state. Presumably, this is due to either (a) suppression of thermal modes through imposed fields or boundary conditions or (b) high thermal conductivity carrying away thermal energy. *As shown in Section 3.5 below, theoretical analysis predicts the charged leaves scatter or reflect electromagnetic radiation in the infrared and microwave regions. The infrared and microwave regions are commonly known to be associated with thermal vibrational and rotational modes for common types of matter (e.g., human tissue). This explains why the charged leaves exhibited thermal disruption effects.*

2.5 Effects of Charge Sign, Leaf Morphology, and Orientation

All of the experiments described above refer to charging the leaves with a negative charge before grounding the electroscope terminal. The attractive state could also be produced with a positive net charge. First, a glass rod was charged positively by rubbing it on a wool cloth. Then, the positively charged glass rod was touched to the electroscope terminal to transfer positive charge to the electroscope leaves. Then, the electroscope terminal was grounded to produce the attractive state. If desired, a positively charged glass rod could be touched again to the electroscope terminal to transfer some excess positive charge to the leaves causing them to repel at the bottom. This produced a state with attraction in the middle and repulsion at the bottom of the leaves analogous to Figure 3(B) except with a positive excess charge. However, if this state was left alone after about 15 minutes the excess positive charge in the repulsive portion of the leaves would be spontaneously dissipated, presumably transferred to surrounding air molecules. This left the electroscope leaves in the attractive state with the repulsive portion removed; that is, the charged leaves ended up in a state analogous to Figure 3c (but with positive net charge on the leaves) having the attractive state throughout the leaves. This shows the attractive state can be produced with either negative or positive charging.

In the early experiments (1990-1994), I also studied the effects of small scratches on the metal layer of the leaves. These small scratches removed small portions of the metal layer such that the plastic dielectric was not coated with any metal where scratched. However, these scratches did not extend the full width of the leaves, so there was still a metallic conducting path connecting the top to the bottom of the leaves. I observed the attractive state could still be produced with scratches on the leaves, but that it was produced with more difficulty and was less vigorous. The mean lifetime of currents produced by rotating the leaves was shortened when scratches were present.

Finally, I would like to comment on the results when the leaves were turned around. In the latter leaves containing a dielectric film on both sides, the attractive state could be induced either when the gold sides faced inwards or outwards. In the (1990-1994) leaves which had gold on one side and dielectric on the other side of the aluminum layer, the attractive state could be produced when the gold sides faced outwards but not stably produced when the gold sides faced inward. For the (1990-1994) leaves, I performed x-ray photoelectron spectroscopy that showed the gold side was comprised mainly of gold with a small amount of tantalum. I measured the total thickness of the (1990-1994) leaves to be approximately 1 micron.

3. Theoretical Results

3.1 Attraction of opposite net charges ruled out

Normally, a positive charge is electrically attracted to a negative charge. Thus, one hypothesis to be examined is whether one of the two leaves has a net positive charge while the other has a net negative charge leading to electrostatic attraction between the two leaves. If this hypothesis were true, then adding a similarly signed net charge to both leaves would cancel the attraction between them. Experiments show this is not the case. Specifically, when a large excess of the same sign net charge is added to both leaves, they repel at the bottom while they still attract near the middle as shown in Figure 3 and Video 2. On rare occasions this can be flipped with the large excess charge accumulating near the middle and attraction remaining near the bottom. Only when a much larger excess of like net charge is placed on the two leaves does the electrostatic repulsion destroy the attractive force between them. These experiments prove that the attractive interaction is not due to a net positively charged leaf attracting a net negatively charged leaf.

3.2 Casimir force ruled out

The Casimir force describes the interaction between two parallel conducting plates placed a small distance apart:[1]

$$F_{\mathrm{Casimir}} = \frac{\hbar c \pi^2}{240}\frac{1}{d^4} \tag{1}$$

where d is the distance between the plates, c is the speed of light in vacuum, and $\hbar$ is Planck's constant divided by 2π. The Casimir force is due to boundary conditions imposed by the conducting plates on the zero-point electromagnetic energy of the vacuum.[1] These boundary conditions lower the vacuum zero-point energy, thereby producing an attractive force between the two plates.[1] For thin conducting plates placed 1 mm apart, the pressure due to the Casimir force is 1.3×10^{-15} Nt/m^2. Because this Casimir force pressure is twenty orders of magnitude smaller than atmospheric pressure, we can safely say its contribution is negligible. Therefore, it cannot explain the Manz effect.

3.3 First-order result of the space opening and closing reaction ruled out

According to Space Mixing Theory, the dimensionality of physical space changes as a function of position.[2] Over macroscopic distances, the small changes in dimensionality manifest themselves as electric fields.[2] Elementary wavelets in spacetime diffuse from lower to higher dimensionality, because there are more paths leading in the direction of higher dimensionality than in the direction of lower dimensionality. Suppose electric charges are regions of high or low dimensionality that act as sinks or sources of spacetime, respectively, as shown in Figure 5. Regions of spacetime having more than three independent spatial dimensions would undergo the space closing reaction in which the excess dimensions collapse. Since spacetime diffuses from lower to higher dimensionality, an electric charge with high dimensionality would achieve steady state when the rate of excess degrees of freedom collapsing by the space closing reaction equals the rate of degrees of freedom diffusing into the space. Regions of spacetime having fewer than three independent spatial dimensions would undergo the space opening reaction in which new dimensions are generated. Since spacetime diffuses from lower to higher dimensionality, an electric charge with low dimensionality would achieve steady state when the rate of new degrees of freedom generated by the space opening reaction equals the rate of degrees of freedom diffusing out of the space.

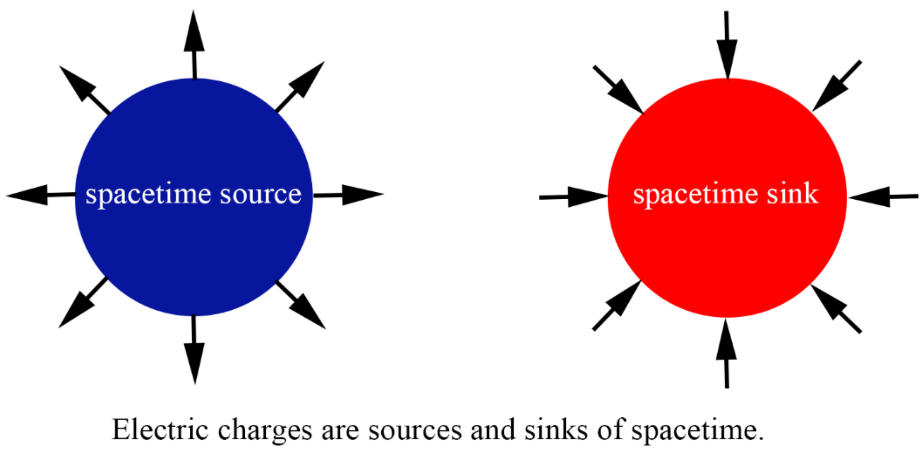


Figure 5: Electric charges are sources and sinks of spacetime

The space opening and closing reaction generates and destroys degrees of freedom in physical space. There is exactly one independent location in physical space per degree of freedom.[3] Consequently, the creation or destruction of degrees of freedom cause the volume of physical space to increase or decrease, respectively. Two parallel plates containing like charges with the appropriate sign to produce a high dimensionality on and between the plates would have an associated space closing reaction. This space closing reaction would deplete spatial volume surrounding the plates, thereby causing the two plates to slowly move towards each other. Two parallel plates containing like charges with the appropriate sign to produce a low dimensionality on and between the plates would have an associated space opening reaction. This space opening reaction would generate spatial volume surrounding the plates, thereby causing the two plates to slowly move away from each other. Thus, a first-order result of the space opening and closing reaction changes from attractive to repulsive interaction between the two plates as the sign of the like net charges on the two plates is switched. Because my experiments showed the attractive state between two like charged parallel plates can be produced by charging both plates either positively or negatively, a first-order result of the space opening and closing reaction is definitively ruled out.

Moreover, it can readily be shown that the volume generation and depletion by the space opening and closing reaction is many orders of magnitude smaller than the observed force. The Lorentz symmetry emerges for length scales large enough that the three backtracking motion channels (associated with the strong nuclear interaction) compact to form a single macroscopic time dimension. For a proton, the effective charge radius is on the order of approximately 10^{-15} m.[4] According to Space Mixing Theory, this represents the distance over which the backtracking motion channels (representing the quark color channels that carry the quark charges) compact to form a single macroscopic time dimension that carries the proton's charge. Within the Lorentz symmetry, the maximum non-tunneling particle velocity is the speed of light in vacuum, c = 299792458 m/s. Therefore an absolute upper bound on the space opening and closing reaction is a rate of space generation or depletion of

$$\text{rate} < 4\pi\left(10^{-15}\,\text{m}\right)^2 c/e = 0.0235\,\frac{\text{m}^3}{\text{Coul}\bullet\text{s}} \qquad (2)$$

where e = $1.602176565\times10^{-19}$ Coul is the proton's charge. This upper bound corresponds to the surface (with area $4\pi r^2$) moving inward or outward at the speed of light. As an example, consider two parallel plates containing like charges sufficient to produce an electric field of one-tenth the dielectric breakdown strength of air. The dielectric breakdown strength of air is approximately 3×10^6 volt/m.[5] For 3×10^5 volt/m, the total surface charge density of the two plates combined is

$$2\sigma = 2\varepsilon_o E = 2\left(8.854187\times10^{-12}\,\text{farads/m}\right)\left(3\times10^5\,\text{volt/m}\right) = 5.3\times10^{-6}\,\text{Coul/m}^2 \qquad (3)$$

where $\varepsilon_o = 8.854187\times10^{-12}\,\text{farads/m}$ is the vacuum permittivity. Combining Eqs. (2) and (3) yields

$$\text{closure\_velocity} < \left(0.0235\,\frac{\text{m}^3}{\text{Coul}\bullet\text{s}}\right)\left(5.3\times10^{-6}\,\frac{\text{Coul}}{\text{m}^2}\right) = 1.25\times10^{-7}\,\frac{\text{m}}{\text{s}}\,. \qquad (4)$$

Therefore, volume depletion (generation) by the space closing (opening) reaction would cause the two plates to move towards (away from) each other at a velocity less than 1.25×10^{-7} m/s, which is many orders of magnitude too small to explain the observed attraction between the two charged plates. In other words, the observed attraction between the two like-charged plates is due to something besides a first-order result of the space opening and closing reaction.

3.4 Electric polarization not the primary effect

Neutral objects can be attracted to statically charged objects through electric polarization. For example, a balloon rubbed on a person's hair acquires a static charge. This charged balloon can then be made to stick to a wall, a piece of paper, or other neutral objects. The static charge in the balloon induces dipole moments in the neutral object to produce the attractive force. When a charged plastic rod is brought nearby to the electroscope leaves, the electroscope leaves are attracted to the charged plastic rod through the electric polarization effect. Even though the electroscope leaves exhibit the electric polarization effect, the experiments and theoretical analysis described below show electric polarization is not the primary cause of the Manz effect.

First, we consider the hypothetical case of two parallel infinite planes charged with the same sign of uniform charge density. The electric field magnitude between these two planes is zero, while the electric field in the outer space not between the plates is $E = \sigma / \varepsilon_o$ where σ is the charge density on each plate. Now consider the case in which a thin dielectric layer is placed on one or both sides of each plate with a gap of vacuum still remaining in part of the space between the two plates. In this case, each dielectric layer will be polarized via electric polarization. The electric field in the gap of vacuum remaining between the two plates is

$$E_{gap} = \sum_i \sigma_i^{left} / \varepsilon_o - \sum_j \sigma_j^{right} / \varepsilon_o \tag{5}$$

where $\{\sigma_i^{left}\}$ are the charge layers to the left of the vacuum gap and $\{\sigma_j^{right}\}$ are the charge layers to the right of the vacuum gap. Since each dielectric layer produces electric polarization charges of equal and opposite sign, the electric field in the vacuum gap is not effected in any way by each dielectric layer. Since the left and right plates have equal net charges, the electric field in the vacuum gap between the two plates is zero: $E_{gap} = 0$. Since the electric field in the vacuum spaces between and surrounding the two uniformly charged plates is independent of the dielectric layers, classic electrostatic theory does not predict any change in the force between the two plates when dielectric layers are added. From this we conclude two parallel infinite planes charged with the same sign of uniform charge density and coated with one or more dielectric layers would not attract each other through simple electric polarization.

As an alternative, we now consider the "trapped charge with electric polarization hypothesis". For example, suppose that when the electroscope is charged and then grounded, that during the grounding step one of the two leaves is not in good electrical contact with the electroscope terminal. In such case, classic electrostatic theory predicts the well-grounded leaf will acquire a net charge whose sign is opposite to the sign of the net charge of the non-grounded leaf. In such case, one leaf would have positive net charge and the other leaf would have negative net charge leading to an attractive force between them. This case has already been discussed and ruled out in Section 3.1 above. Specifically, the attractive state remains even when an excess of like charges is placed on the two leaves as shown in Figure 3 and Video 2. I also performed additional experiments ruling out the "trapped charge with electric polarization hypothesis". In the early 1990's experiments using leaves containing a dielectric layer on only one side of the metal layers, I noticed the attractive bound state remained stable when the metal layer of leaf 1 was electrically connected (via conducting wire or fingers) to the metal layer of leaf 2 at the top or bottom when the leaves were held apart so the attractive bound phase migrated to the middle portion of each leaf. However, touching the metal layer of either leaf in the section where the attractive bound phase resided instantaneously destroyed the attractive bound state. These experiments showed the attractive bound phase flowed freely like a liquid to the region where the two leaves were closest to each other. If the two activated leaves were manually pulled apart so as to make their tops (where the electroscope terminal was attached) the closest positions between the two leaves, the attractive bound phase immediately discharged and ceased existence. As explained in Section 2.2, the attractive bound state was stable when left undisturbed for days. These experiments prove that the attractive bound state is not due to poor electrical contact between the two leaves with associated "trapped charge". Rather, the Manz effect involves a thermodynamically stable new electronic phase that responds consistently to its environment.

3.5 Explanation: Vacuum electromagnetic scattering

Another hypothesis to be examined is that scattering of vacuum electromagnetic waves produces the attractive force. The energy density of an electromagnetic field is given by

$$u = \frac{1}{2}\vec{E} \bullet \vec{D} + \frac{1}{2}\vec{B} \bullet \vec{H} \tag{6}$$

where $\vec{E}$ is the electric field, $\vec{D}$ is the electric displacement field, $\vec{B}$ is the magnetic field, and $\vec{H}$ is the H-field.[6] In free space, this equation simplifies to

$$u = \frac{1}{2}\varepsilon_o E^2 + \frac{1}{2}\frac{B^2}{\mu_o} \tag{7}$$

where $\mu_0 = 1.257 \times 10^{-6}$ henry per meter is the vacuum permeability. The energy increase of an electromagnetic (EM) wave when penetrating an electrostatic field E_{device} over an effective volume

$$V_{effective} \approx \lambda^3 \tag{8}$$

is approximately

$$\Delta U_{penetration} \approx \frac{1}{2}\varepsilon_0 \left[\left(E_{device} + E_{EM\ wave} \right)^2 - E_{EM\ wave}{}^2 - E_{device}{}^2 \right] \lambda^3 \approx \varepsilon_0 E_{EM\ wave} E_{device} \lambda^3 . \tag{9}$$

The electric field of an EM wave, $E_{EM\ wave}$, has an approximately sinusoidal pattern that oscillates between positive and negative. If E_{device} is approximately constant over the EM wave's effective volume, $V_{effective} \approx \lambda^3$, then the average interaction energy between $E_{EM\ wave}$ and E_{device} will be zero. However, if E_{device} changes abruptly from some nonzero value E_{plate} on one side of a thin charge plane to approximately zero on the other side of this thin charge plane, then $\Delta U_{penetration}$ will change abruptly as the EM wave tries to cross the charge plane. In this case, the interaction (or penetration) energy will be maximized when half of the EM wave crosses the charge plane. (This assumes the charge plane is confined to a thickness much smaller than the EM wave's wavelength.) For a parallel-plate geometry with like charges, the electric field magnitude outside the two plates is

$$E_{plate} = 2 \times \sigma / (2\varepsilon_o) = \sigma / \varepsilon_o \tag{10}$$

where σ is the charge density on each plate. Thus,

$$\Delta U_{penetration} \approx \varepsilon_0 E_{EM\ wave} E_{plate} \left(\lambda^3 / 2 \right) = E_{EM\ wave} \sigma \left(\lambda^3 / 2 \right) \tag{11}$$

where the effective volume $\lambda^3 / 2$ corresponds to half the EM wave on each side of the charge plane. If this energy change is sufficiently large, it will cause the EM wave to be back-scattered or reflected off the charge plane. Here, EM wave is a general term that includes any of the following: (a) a photon (i.e., a quantum of electromagnetic radiation), (b) zero-point EM waves comprising vacuum oscillations, or (c) EM waves generated by matter. The energy required to produce a scattered EM wave of wavelength λ can be approximated by the energy of a photon of the same wavelength

$$U_{EM\ wave} \approx U_{photon} = hc / \lambda . \tag{12}$$

EM wave scattering or reflection is expected to occur when $\Delta U_{penetration} \gtrsim U_{photon}$. EM wave scattering is expected to be negligible when $\Delta U_{penetration} \ll U_{photon}$. For a photon, about half of its energy is caused by its electric field and the other half is caused by its magnetic field. The characteristic electric field of the photon can be roughly approximated by dividing its electric energy by its effective volume ($\sim\lambda^3$):

$$E_{photon} \approx \sqrt{\frac{(1/2)hc/\lambda}{\lambda^3 \varepsilon_o}} . \qquad (13)$$

Approximating $E_{EM\ wave} \approx E_{photon}$, substituting Eq. (13) into (11), and equating to (12) yields the cutoff photon wavelength:

$$\lambda_{threshold} = \left(8hc\varepsilon_o\right)^{1/4} \sqrt{\frac{1}{\sigma}} . \qquad (14)$$

The momentum of a photon of wavelength λ is $p = h/\lambda$. Upon scattering, the momentum changes from $-p$ to $+p$, leading to a momentum change of $2h/\lambda$. This occurs at a frequency of c/λ and a striking area of $\sim\lambda^2$. Hence, this produces a pressure due to scattering of approximately

$$P_{scatter}^{\lambda} \approx \frac{2hc}{\lambda^4} . \qquad (15)$$

Half the incoming electromagnetic waves will be right-traveling and half will be left-traveling. The right-traveling incoming electromagnetic waves are scattered off the left plate and the left-traveling incoming electromagnetic waves are scattered off the right plate.

For λ greater than approximately twice the leaf size, the incoming electromagnetic wave will interact with the leaves over a volume significantly smaller than the EM wave's wavelength. Accordingly, the electric field of the leaves will scatter long-wavelength incoming electromagnetic waves inefficiently. The charged leaves should strongly scatter electromagnetic waves with wavelengths ranging from $\lambda_{threshold}$ up to approximately twice the leaf size:

$$\lambda_{threshold} \lesssim \lambda_{scattered} \lesssim 2\sqrt{A} . \qquad (16)$$

Eq. (16) describes only approximate boundaries. In general, the static charge layer should not scatter electromagnetic waves for $\lambda \ll \lambda_{threshold}$ and $\lambda \gg 2\sqrt{A}$. The total scattering pressure equals the scattering pressure at each wavelength summed (or integrated) over the range of wavelengths being scattered. Since the scattering pressure is approximately inversely proportional to the wavelength to the fourth power (Eq. (15)), the contribution to the scattering pressure becomes negligible for very large wavelengths. Therefore, the total scattering pressure should be some multiple of the nominal scattering pressure at the threshold wavelength:

$$P_{scatter} = \sum_{\lambda} P_{scatter}^{\lambda} \approx f \times \frac{2hc}{\left(\lambda_{threshold}\right)^4} \approx f\, \frac{\sigma^2}{4\varepsilon_0} . \qquad (17)$$

Eqs. (17) is precise, because all of the uncertainties have been rolled into the adjustable parameter f. A precise calculation of the parameter f is beyond the scope of this article. More careful experiments and theoretical analysis are required to obtained a precise value for the parameter f. A precise analysis should include the integration of scattering probabilities and force contributions over wavelengths.

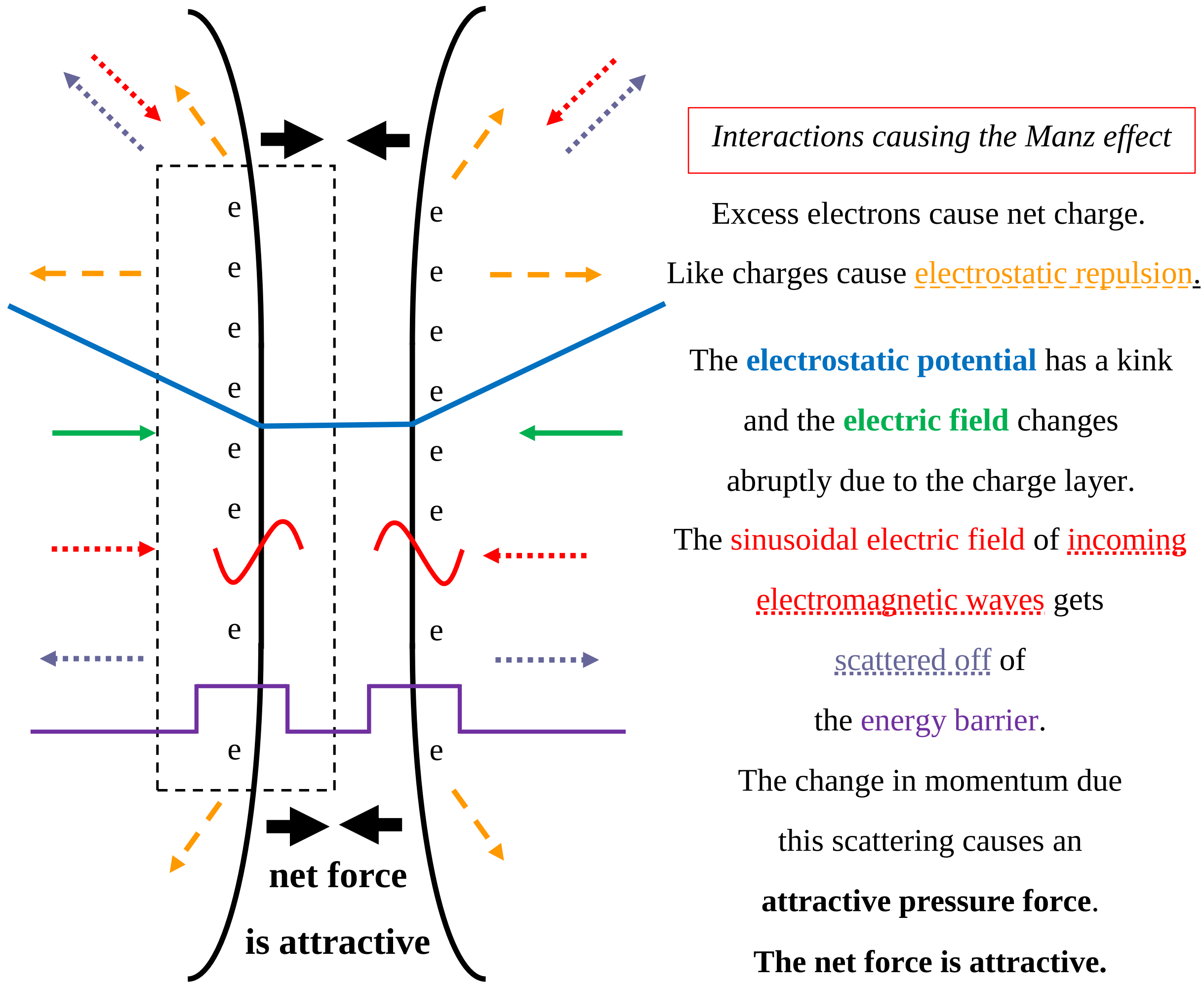


Figure 6: *What causes the Manz effect?* The thin excess charge layer on each plate causes an abrupt change in the electric field. This can be inferred from Gauss's Law using the imaginary dotted box as a control volume. By symmetry, the electric field for the imaginary box side in the middle of the two leaves is zero. The electric flux thus passes almost entirely through the other side of the dotted box. This abrupt change in the electric field causes an energy barrier for incoming electromagnetic waves. Incoming electromagnetic waves with an appropriate range of wavelengths are scattered off this energy barrier. This change in momentum due to scattering causes a pressure force that pushes the two charged plates towards each other. This creates the unusual net attractive force between two plates having electrostatic net charges of the same sign.

The total scattering force between the plates is

$$F_{scatter} = AP_{scatter} \approx f\frac{\sigma^2 A}{4\varepsilon_0} \tag{18}$$

where A is the plate area and the positive sign indicates an attractive force. For the same parallel plate geometry, the standard repulsive Coulomb force is given by

$$F_{\text{Coulomb}} = -\frac{\sigma^2 A}{2\varepsilon_0} \tag{19}$$

where the negative sign indicates a repulsive force. The net attractive force is thus given by

$$F_{\text{net attractive}} = F_{\text{scatter}} + F_{\text{Coulomb}} \approx (f-2)\frac{\sigma^2 A}{4\varepsilon_0}. \tag{20}$$

According to Eq. (20), the net force will be attractive for f > 2 and repulsive for f < 2. Since the experiments described in this paper exhibit an attractive force, it necessarily follows that f > 2. For f = 4, the attractive force would be equal in magnitude and opposite in direction to the standard Coulomb repulsive force. It is crucial to note that this attractive force arises from the scattering of various types of EM waves: (a) photons (i.e., quantums of electromagnetic radiation), (b) zero-point EM waves comprising vacuum oscillations, and (c) EM waves generated by matter. In summary, this analysis can explain the origin of attraction between two parallel plates having same signed static charges.

As an example, consider charging the plates to produce an electric field of one-tenth the dielectric breakdown strength of air. The dielectric breakdown strength of air is approximately 3×10^6 volt/meter. [5] For 3×10^5 volt/meter, Eq. (14) gives a threshold wavelength of 1.2 μm, which is in the infrared range. Leaves 13 mm in width would be expected to strongly scatter waves up to about 2.6 cm in wavelength, which is in the microwave range. Thus, for normally accessible conditions, the charge state would scatter electromagnetic waves within the infrared and microwave regions, but not significantly at longer or shorter wavelengths.

Figure 6 summarizes the interactions causing the Manz effect. Two parallel thin metallized dielectric foils contain an excess of electrons. (The effect can also be produced using a deficiency of electrons to produce plates with positive net charge.) Normal electrostatic forces would cause these two plates to repel each other (aka Coulombic repulsion). However, the electrostatic potential has a kink at the confined charge layers. This causes the electrostatic field to change abruptly near the charge layer. The sinusoidal electric field of an incoming electromagnetic wave exhibits an energy barrier as half of the wave crosses the charge plane. This energy barrier causes incoming electromagnetic waves of an appropriate frequency range to backscatter or reflect. The change in momentum due to this scattering or reflection causes an attractive pressure force that pushes the two plates together. The net force is attractive and overcomes the Coulombic repulsion.

4. Conclusions

Traditional physics theory holds that opposite electrostatic charges attract and like electrostatic charges repel. Here, I have shown this is not true under some circumstances. Specifically, I have shown that macroscopic objects having electrostatic charges of the same sign can exhibit strong electrostatic attraction. As a specific example, I showed a pair of parallel thin plates containing metal and dielectric layers can exhibit strong attraction rather than repulsion when charged with like electrostatic charges. To the best of my knowledge, this is the first report of electrical attraction between two macroscopic collections of static charge carriers having the same sign. It is most noteworthy that this attractive force leads to an electronic phase transition that effectively liquefies the charge carriers on the charged leaves. When rotated, this charge carrier liquid exhibited free current lifetimes of several seconds. This *Manz effect* is caused by the scattering of electromagnetic oscillations from the electrostatic potential kink that occurs at the position of each confined charge layer. Theoretical analysis and preliminary experiments indicated this electromagnetic scattering is most active within wavelength ranges associated with thermal molecular motions, particularly the infrared and microwave regions associated with thermal vibrations and rotations. This suggests devices incorporating the effect should find applications for shielding electronic circuits and other objects from electromagnetic oscillations in the infrared and microwave regions.

5. Acknowledgements

I sincerely thank The University of Toledo physics department for temporarily loaning me an electroscope and foils for experiments on static electricity when I was an undergraduate student there. I first discovered what is now called the Manz effect when using this borrowed electroscope and foils to perform experiments on static electricity in my rented apartment in Toledo, Ohio. Although the precise date of these first experiments is unknown, they were performed when I was an undergraduate student at The University of Toledo (1990-1994).

Although I recognized immediately that something unusual was occurring, it took decades of part-time thought and experimentation to discover the underlying cause of the effect. After purchasing my own electroscope and foils, additional experiments were performed over a period of many years. My graduate project research at Purdue University focused on a completely different topic: experimental and computational catalysis. However, I spent a small fraction of my time continuing research on this electronic phase transition. Eleven low-resolution Polaroid photographs survive that were taken on 13 October 1998. Four of these are shown in Figure 1. After graduate school, I occasionally spent some time studying this effect as a post-doc at the Georgia Institute of Technology and assistant professor at New Mexico State University. During 2015, the electromagnetic shielding application became of interest to the National Aeronautics and Space Administration (NASA), because shielding electronic circuits from electromagnetic noise in space is a key consideration for spaceflight applications. I sincerely thank NASA and the New Mexico Space Grant Consortium for funding part of this work during the past year. I thank Pat Hynes, director of the New Mexico Space Grant Consortium, and Dr. Manohar Deshpande of the NASA Goddard Spaceflight Center, for their encouragement.

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