Analysis of Lockyer Cubes

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Thomas Lockyer claims many discoveries related to the flow of **E**, **H** and **S** fields around a cube [1-3]. He claims that there exist only five ways in which these three vector fields can flow through the eight corners of a cube, and that these five ways correspond to five fundamental particles. Unfortunately Lockyer has never specified the rules governing this flow, nor has he proven that only five such possibilities exist. This paper intends to list the applicable rules, and exhaustively explore these possibilities, to confirm or deny Lockyer's claims.

1. Introduction

In electrodynamics, the **E**, **H** and **S** vectors represent certain physical properties describing radiation and light propagation. Specifically **E** symbolizes the electric field, **H** the magnetic field, and **S** the Poynting or energy flow field. Not independent, they are defined to satisfy $\mathbf{S}=\mathbf{E}\times\mathbf{H}$, according to the right hand rule convention. However, for the purpose of this paper, we imagine them strictly as a mathematical set of flows around the edges of a cube, which behave according to a specific set of rules, and not necessarily satisfying $\mathbf{S}=\mathbf{E}\times\mathbf{H}$ everywhere by the same convention. The question of *why* anyone might wish to analyze the flow of these vectors in this way, or what it might mean in terms of particles, is secondary for this purpose, though I will comment on these questions in the conclusion.

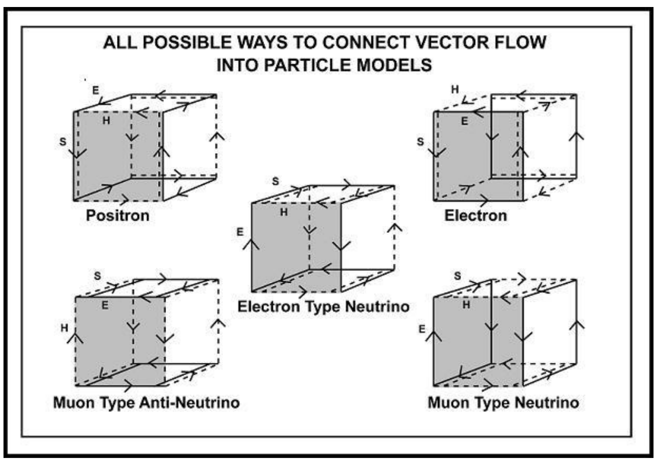

Fig 1. Lockyer's Vector Particle Physics (VPP) model, based on the flow of vectors **E**, **H** and **S** along the edges of a cube [1-3].

In the Lockyer model (Fig. 1), **E**, **H** and **S** vectors flow around a cube according to the following rules:

1. Fields flow only along edges, between adjacent corners.
2. All three fields flow into and out of each corner.
3. No field may exit along the same edge it entered.
4. Entering **E**, **H** and **S** fields are mutually orthogonal.
5. Exiting **E**, **H** and **S** fields are mutually orthogonal.

I believe this short list suffices to summarize the model, though many additional consequences may be drawn from it, as we'll discover. In this paper the "flow of vectors" or flow of a field" refer to the path that each **E**, **H** and **S** follow around the cube, not necessarily to physical fields. A few immediate conclusions:

6. Flow paths never end, but circulate (by 1,2).
7. Each field flows along exactly 8 of the 12 cube edges, since a cube has 8 corners (by 1,2,3).
8. Each field flows out of each corner $90°$ from the direction it flowed in, either in a right- or left-handed sense (by 1,2,3).
9. No two vectors along a given edge can flow in the same direction, since they would then enter and exit corners in parallel (by 4,5).
10. Each edge may have at most two field flows, which must be in opposite directions (by 9).
11. Each edge must have exactly two field flows, since 8 edges for 3 vectors demands 24 flows along 12 edges, precisely 2 per edge (by 7,10).
12. Each pair of two fields (**EH**, **HS** or **SE**) must share exactly 4 of the 12 edges, else the individual fields could not flow along exactly 8 edges (by 7,11).
13. The shared edges for each pair may not meet at a corner, else the third vector would have to flow back (by 3).
14. All three fields must curl through each corner (or node) at $120°$ either CW or CCW (*not* RH or LH), else different fields would flow along the same edge (by 8,11).
15. The relation between **E**, **H** and **S** is either right- or left-handed, both entering and exiting. That is, $\mathbf{E}\times\mathbf{H}=\pm\mathbf{S}$, where positive is RH, and negative LH (by 4,5).
16. The sense (RH or LH) of the entering triple is opposite to the sense of the exiting triple (by 14,15).

The paper will discuss these rules and conclusions in greater detail, but now it's time to proceed with the analysis.

2. Cube Orientation & Labels

Three-dimensional concepts are often difficult to visualize, let alone analyze. Thus, it will prove helpful to actually have a cube of some kind in your hands as you read this: a Rubik's cube works great. We'll begin by selecting a consistent numbering system for the corners of a cube. Though the choice presented may at first seem arbitrary, its advantages will hopefully become apparent. We'll label the corners +1 to +4 and -1 to -4, such that the four corners of each of the six cube faces are labeled ±1, ±2, ±3 and ±4, in some order. Furthermore, each corner and its antipode will have opposite "polarity". I.e., the corner marked +1 will sit as far as possible from the corner labeled -1, etc.

Now orient your cube so that two corners become the "north" and "south" poles. Label the "north pole" +3 and the "south pole" -3. Notice that three of the six remaining corners reside in the "northern hemisphere" and three in the "southern". Label the three northern corners +1 -2 +4 in a CCW (counter clockwise) order as you look down from the "north". Label the southern corners according to their opposites -1 +2 -4. I strongly urge you to lay your hands on a physical cube, and label the numbers, maybe with the sticky part of a post-it note. What follows will be hard to understand without a tangible object. There are several things to notice.

Again treating +3 and -3 as poles, note that a 120° rotation about the pole axes amounts to a shift of 3 modulo 9 in each of the six remaining corners. I.e. $+1 \to +4$, $+4 \to +7 = -2$, $-2 \to +1$ in the "northern hemisphere", and the reverse for the corners in the "southern hemisphere". Who'd have thought that modulo 9 arithmetic, touted by Marko Rodin [4], could be applied to a 8-cornered cube? But there it is. One may conceive of the"9" or "0" as in the center of the cube.

Yet another way to visualize the rotations of a cube is as part of the S_4 symmetric group, which contains the $4! = 24$ possible permutations of the number set $(1,2,3,4)$. Ignoring for now the sign of each corner, we can find all the 24 possible face–orientations (6 faces in 4 orientations each) uniquely on some face in some orientation. Just choose a fixed way to count the corners of a given face, say, clockwise from the upper left (UL) corner, i.e. UL, UR, LR, LL. Try to find $(3,2,4,1)$, $(1,3,2,4)$, and of course $(1,2,3,4)$. The signs provide additional information, but we'll let that tangent go.

Alternately, S_4 could be interpreted as the 24 possible rotations to get from any particular face to another. Rotate up to 3 times about the 3 face axes, 2 times about the 4 corner axes, 1 time about the 6 edge axes, or do nothing. This gives $3 \cdot 3 + 2 \cdot 4 + 1 \cdot 6 + 1 = 24$ possible operations. A beautiful thing about finite groups such as S_4 is that they may represent either operations (rotations) or states, since the two bear a one-to-one relationship.

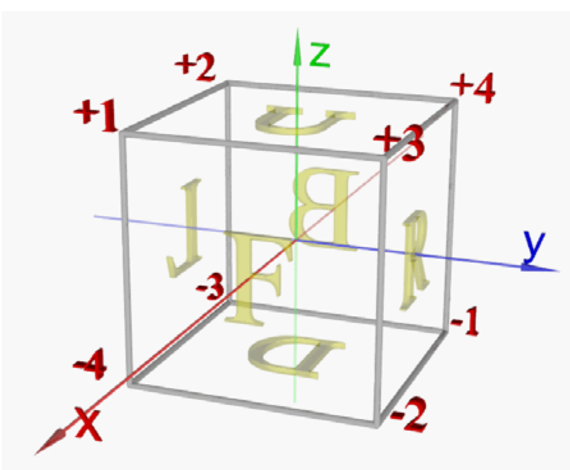

Fig 2. Orientation of the cube. Drawn by Don Mitchell.

With this in mind, now study the patterns you find on each of the faces, and orient your cube as in Fig. 2, so that

+3 -2 -4 +1	F front	-3 +2 +4 -1	B back	*x*-axis
+3 +4 -1 -2	R right	-3 -4 +1 +2	L left	*y*-axis
+3 +1 +2 +4	U up	-3 -1 -2 -4	D down	*z*-axis

Notice that the three axes contain the three possible permutations of the four numbers, with 3 opposite 4 on the F and B faces (perpendicular to the *x*-axis), opposite 1 on the R and L faces (*y*-axis), and opposite 2 on the U and D faces (*z*-axis). Confirm for yourself that FRU is a right-handed system, by letting your index finger (of your right hand) point toward yourself (*x*-axis), your ring finger point to the right (*y*-axis, yes, it's a little awkward), and your thumb point up (*z*-axis).

This numbering system will prove convenient and useful, though we could also label each corner with a $(\pm1,\pm1,\pm1)$ coordinate. In fact, we can even dispense with the 1's, because every coordinate of the cube corners have the same magnitude. Then

+1: (+ - +)	-1: (- + -)
+2: (- - +)	-2: (+ + -)
+3: (+ + +)	-3: (- - -)
+4: (- + +)	-4: (+ - -)

Take a minute to confirm these coordinates with your model, and note that the polar axis (±3), through which our original north and south poles pass, is not the *x*-, *y*- or *z*-axis, but the diagonal along (+ + +).

With this established, it should now be easy to visualize the flow of each field in various patterns along the edges of a cube. In fact, each field flow can be expressed simply as some sequence through the eight numbers representing the corners, as in

+3 -2 -1 +4 +2 -3 -4 +1 +3

or -3 +2 +1 -4 -2 +3 +4 -1 -3

or +3 +1 +2 +4 +3 AND -3 -1 -2 -4 -3

Try it!

3. Possible Path Patterns

We must first determine the possible paths for field flows, and only then determine the possible combinations of those flows that satisfy the rules for all three fields. One might initially suspect that there are numerous ways to traverse the corners of a cube, but in reality, there are only two, given in the above examples. These two possibilities could be called the "single path" (aka the "wicket") and the "double loop".

The double loop is the easiest to visualize, consisting of two square circuits around two opposite faces. In the above example, the two squares are U (up) and D (down), with the first circulating in a LH sense and the second in a RH sense. (By "sense" I mean if you curl your hand in the path of the flow, which hand causes your thumb to point outward? If right, it flows in a RH sense, and if left, LH.)

There is an ambiguity in the double loop, since it is "amphichiral", or superposable with its own mirror image. If the fingers of your right hand curl in the direction of a given flow around a face, does your thumb point outwards or inwards? We'll choose the convention that right thumb outward (or left thumb inward) has a RH orientation, while the reverse has a LH or orientation, denoted by a bar, as in $\bar{\mathrm{R}}$ or $\bar{\mathrm{D}}$. Now, two opposite faces (say U and D) can have four possible combinations of orientation: UD, U$\bar{\mathrm{D}}$, $\bar{\mathrm{U}}$D or $\bar{\mathrm{U}}\bar{\mathrm{D}}$. Thus, for example, UD means that both U and D faces have a RH (outward) orientation, and R$\overline{\text{L}}$ means that the R face has a LH orientation and the L face has a RH orientation. In this latter case, both circuits travel in the same direction relative to the outside world, but the right thumb points inward on the R side and outward on the L. The combination of polarity of the two sides will be important when we discuss Lockyer's models.

The single path pattern is a bit harder to envision, though you might describe it as two adjacent croquet wickets (3 edges each) joined at the bottoms (2 more edges). Flip it upside down and it retains its shape, except rotated 90° in *xy*. Its projection looks like a "U" in two different directions, for example as a right-side up "U" in the *x*-projection and an upside-down "U" in the *y*-projection. I therefore call this a "wicket" pattern.

You can also visualize it by the faces it separates. In the above example, the front (F), down (D) and back (B) face are separated from the right (R), up (U) and left (L) faces by the path. I would describe this simply as a U*y* (or D*x*) path, meaning that the U face and the two faces in the *y*-direction (R and L) are separated from the other faces. It shouldn't take too much imagination to see that there are only six possible orientations of this path, namely:

U*y* (D*x*)	U*x* (D*y*)
F*z* (B*y*)	F*y* (B*z*)
R*x* (L*z*)	R*z* (L*x*)

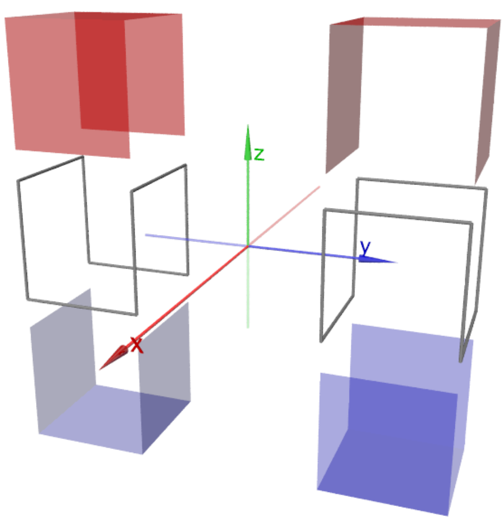

Fig 3a. U*x* (D*y*) and U*y* (D*x*)

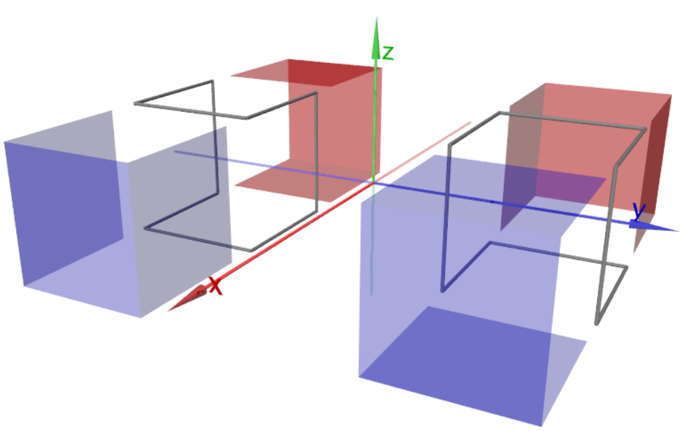

Fig 3b. F*y* (B*z*) and F*z* (B*y*).

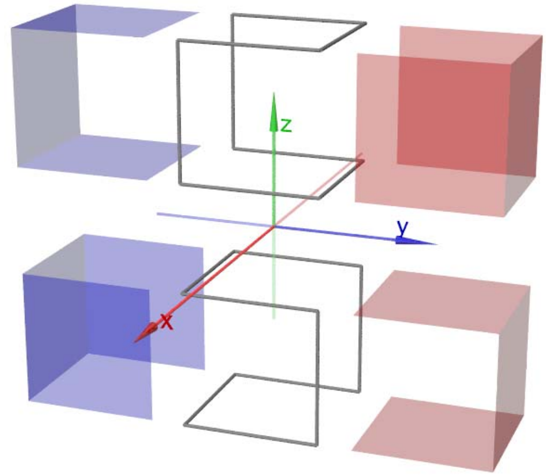

Fig 3c. R*x* (L*z*) and R*z* (L*x*) Drawn by Don Mitchell.

Now the strategy is to start at some corner and move in every possible direction until all possibilities have been exhausted. We'll then see that every possible path becomes either a "double loop" or one of the above six "single paths" (aka "wickets"). The possibilities are surprisingly fewer than you might initially expect, so it won't be difficult or tedious.

Choose +3 as our starting point. Because of the rotational symmetry through 120°, a move to any of the three adjacent corners, +1, -2 or +4, leads to the same result, except the numbers must be shifted by 3 mod 9. Thus, we need only consider sequences beginning "+3 -2". At each corner, we can then proceed to the "right" or to the "left". We exhaust all possibilities by consistently choosing one direction (right) first whenever a choice is possible, and continuing until no more options exist. Each time we reach a "dead end", determine which pattern gets established, back up to the previous choice, and proceed as before. Applying this algorithm, you'll find that there are only six possibilities, as listed below. Of course, it's infinitely more meaningful if you actually pick up the cube you labeled earlier and follow the paths yourself. No amount of writing about it here can replace the "aha" you get when you do this.

+3 -2 -4 +1 +3 …	B	
+3 -2 -4 +1 +2 …	D*y*	Can't go to +4
+3 -2 -4 -3 …	R*z*	Can't go to +2
+3 -2 -1 -3 …	B*y*	Can't go to +2
+3 -2 -1 +4 +3 …	R	
+3 -2 -1 +4 +2 …	U*y*	Can't go to +1

Certainly a more formal and rigorous proof should be performed, but if you actually sit down and systematically exhaust all possibilities, you'll convince yourself that the single- and double-path patterns are the only possibilities. To complete the analysis, the possible patterns beginning with "+3 +4" are L, B*z*, U*x*, L*z*, U, F*z*, and with "+3 +1" are D, L*x*, F*y*, D*x*, F, R*x*, accounting for all 18 paths in our nomenclature. (Of course, half are redundant, since, for example, B and F are paired, and U*y* and D*x* describe the same path.)

To summarize, any given vector can flow in one of two possible ways to satisfy the Lockyer rules:

1. "*Double loop*" – two short paths about opposite faces:

+3 +1 +2 +4 +3	AND	-3 -1 -2 -4 -3	U D
+3 -2 -4 +1 +3	AND	-3 +2 +4 -1 -3	F B
+3 +4 -1 -2 +3	AND	-3 -4 +1 +2 -3	R L

2. "*Wicket*" – one single path in a wicket pattern

+3 -2 -1 +4 +2 -3 -4 +1 +3	Uy (Dx)
+3 +4 +2 +1 -4 -3 -1 -2 +3	Fz (By)
+3 +1 -4 -2 -1 -3 +2 +4 +3	Rx (Lz)
+3 +4 -1 -3 +2 +1 -4 -2 +3	Ux (Dy)
+3 +1 +2 -3 -4 -2 -1 +4 +3	Fy (Bz)
+3 -2 -4 -3 -1 +4 +2 +1 +3	Rz (Lx)

Table 1. Summary of possible Lockyer paths.

If you don't have a Rubik's cube handy, you really should trace these patterns using Fig. 2.

4. Path Combinations

4.1. Three "Double Loops"

Having established only two possible path patterns, the "double loop" and "single path" or "wicket", we now move on to combinations of those patterns, according to the rules for Lockyer cubes. The easiest ones to visualize are those involving double-path patterns. Let the **E** field, say, circulate in an F pattern, **H** in R pattern, and **S** in a U pattern. If we require opposite directions for the two fields along any edge (Rule #9), then the sense of the flow patterns around the adjacent faces must be the same. For example, the **E** field along the front face will flow +3 +1 -4 -2 +3 (F) or +3 -2 -4 +1 +3 ($\overline{\mathrm{F}}$). The **H** field along the right face will flow +3 -2 -1 +4 +3 (R) or +3 +4 -1 -2 +3 ($\overline{\mathrm{R}}$). The two have the edge +3 -2 (in the z direction) in common, and only if both fields have the same sense will they traverse this edge in opposite directions. Perhaps an easier way to visualize this is to observe the direction of the path along some edge using RH or LH orientation (i.e. with your R or L thumb pointing outward and curling your fingers along the path.) Then observe the same edge about an adjacent face. You will find that only when the sense of the two curls is the same will the paths along the adjoining edge be opposite.

Since every face is adjacent to four others, and since all faces are adjacent to the remaining edge, we conclude that all six faces must have the same sense (RH or LH) to satisfy Rule #9, that the two vectors along every edge flow in opposite directions. Therefore, there exist only two solutions consisting of "double loops" that satisfy the constraints of Lockyer Cubes: one with all RH and one with all LH orientations. Lockyer dubs them the *positron* (RH) and *electron* (LH) in Fig. 1.

$$\mathrm{UDRLFB}: \ \textit{positron} \qquad \overline{\mathrm{U}}\overline{\mathrm{D}}\overline{\mathrm{R}}\overline{\mathrm{L}}\overline{\mathrm{F}}\overline{\mathrm{B}}: \ \textit{electron}$$

One might argue for two more possibilities, if we switch the sense of **E-H-S** to **H-E-S**, for example. However, the two actually produce the same result, simply rotated. In the example, **E-H-S** were assigned to rotate around the edges of the F-R-U faces respectively. But since all Lockyer paths must have the same sense, **H** must also flow around the L face in the same sense as around the R face. But F-L-U is a LH system, and would need to be described as L-F-U to be right-handed, corresponding with **H-E-S**.

Indeed, it is at this point where we discover some consequences of Rules 14-16. Judged from outside the cube looking in, we find that around every corner the three flows all circulate in the same CW or CCW sense (Rule #14). However, the relationship between the three fields carries the opposite sense, **E-H-S** vs. **H-E-S**, at adjacent corners (Rule #16). (There are two senses of the word "sense" here, if that makes any sense.) From this, it is apparent that $\mathbf{E}\times\mathbf{H}=+\mathbf{S}$ entering four non-adjacent corners (say +3 -1 +2 -4 in our original notation) and $\mathbf{E}\times\mathbf{H}=-\mathbf{S}$ entering the other four (-3 +1 -2 +4). (Incidentally, the two sets of four corners form two tetrahedrons, also known as the stellated octahedron [5].) Moreover, the **E-H-S** sense of the entering triple is the opposite of the exiting triple (Rule #15).

This difficulty alone might cause those seeking conventional understanding of electrodynamics ($\mathbf{E}\times\mathbf{H}=\mathbf{S}$ because nature says so!!) to dismiss the model. Yet we must never forget that the sense of all these fields is by convention. **E** points from positive to negative charge, **H** curls in a RH sense around positively flowing charge, **S** points in the direction of energy flow. All or only some conventions could be reversed without any change in the physics. Even the curl ($\times$) operation itself takes a RH convention, and is not RH by some law of nature. Still, the change in sense from corner to adjacent corner or from entering to exiting is independent of convention, so we must dig deeper if we want the model to express electromagnetic reality. But I digress.

4.2. Two "Wickets" Plus One "Double Loop"

Now, we want to discover the combinations involving one or more "single path" or "wicket" flow patterns. To begin, we'll find that the number of "wickets" must be even, either 0 or 2, or equivalently that the number of "double loop" flows must be odd, either 3 or 1. We've already dealt with the case of 3 "double loops", so will need only examine the possibilities of 2 "wickets" plus 1 "double loop". Here we'll find only three possibilities, depending on whether **E**, **H** or **S** is the odd man out (a colloquialism meaning one that's different) following the "double loop". These three, combined with the two flows already mentioned, will form the five possible flows claimed by Lockyer.

We now get to the meat of understanding Lockyer cubes. Rules #12 and #13 tell us that each pair of two flow patterns (**EH**, **HS** or **SE**) must share exactly four edges, and that these four edges may not touch. So now we need to exhaust all the possible ways to choose four non-touching edges. There are only two.

Returning to our cube, let's begin by choosing an arbitrary edge, say, +3 $\to$ +4. Four of the remaining edges are already eliminated from our possible set (+3 $\to$ +1, +3 $\to$ -2, +4 $\to$ -1, +4 $\to$ +2), since they touch +3 $\to$ +4. Of the 7 remaining edges, 2 are across a face (-1 $\to$ -2 across R, +1 $\to$ +2 across U), 1 is across the center of the cube (-3 $\to$ -4), and the remaining 4 all touch the cross-center edge (-3 $\to$ -1, -3 $\to$ +2, -4 $\to$ +1, -4 $\to$ -2). So we need to try choosing each of these three as our second edge.

If we choose the second edge across a face, say +1 $\to$ +2 across U, we eliminate two more edges as candidates for our set, namely -4 $\to$ +1 and -3 $\to$ +2, leaving only the four edges framing the opposite face (D), namely -3 → -1, -1 → -2, -2 → -4, -4 → -3. Out of these, we can choose two non-touching pairs: -1 → -2, -4 → -3 and -3 → -1, -2 → -4. These turn out to exhaust the possible ways of choosing four non-touching edges:

1. Four parallel edges, along the x, y or z axis (Ex. +1 → +2, +3 → +4, -1 → -2, -3 → -4, along the x-axis).
2. Cross pattern: Two sets of edges on opposite faces, oriented relatively at 90° (Ex. +1 → +2, +3 → +4, -3 → -1, -2 → -4, the first two on the U face along x, the latter two on the D face along y.)

Visualize the second possibility with two sets of two fingers criss-crossing on top of each other.

But are there other possibilities? Let's check. Returning to our original chosen edge, +3 → +4, what options do we have if we choose the opposite edge, -3 → -4, as the second in our set? Only two non-touching edges remain, +1 → +2 and -1 → -2, creating parallel set #1 above. All right, what if we choose one of the edges, say -3 → -1, diagonally across from +3 → +4? This eliminates seven edges (four each less +4 → -1, which touches both), leaving only 3 non-touching candidates: +3 → +4, -2 → -4, and -4 → +1. The last creates a set of three mutually diagonal edges (+3 → +4, -1 → -3, -4 → +1) with no untouched edges remaining, so can't qualify for a four-edge set. Either of the first two result in cross pattern set #2 above.

So that's it! There are no other possibilities. Now what?

Now we get to the million dollar insight. (Well, $1.25 maybe.) The acceptable flow patterns, "double loop" and "wicket", must contain two sets of either four parallel edges (#1) or the cross pattern (#2), since they must pair up with the other flow patterns along those four edges. The "double loop" could be interpreted as two sets of parallel patterns, or as two sets of cross patterns. However, the "wicket" can only be interpreted as one of each (example below). As a reminder, there are three sets of either parallel or cross patterns, each set containing **EH**, **HS** or **SE**. So if each vector contributes to half of the patterns it flows through, there must be an even number of "wicket" flows, or we would wind up with half contributions to the various patterns, which is impossible.

I hope the last paragraph was intelligible for you, since it makes a central point in this paper. Examples may clarify things. The double loop UD consists of eight edges, that can be grouped into fours in two different ways:

(+3 → +1, +2 → +4) (-3 → -1, -2 → -4)
(+3 → +4, +2 → +1) (-3 → -4, -2 → -1)

If the pairs on the left join across rows with the same pairs on the right, we get four parallel edges (case #1). If they join with the pairs in the opposite rows we get a cross pattern (case #2). In the first case, one of the other three vector flow patterns must share the case #1 pattern in the top row and the third flow pattern must contain the case #1 in the bottom row. In the second case, one of the other vector flow patterns must contain the case #2 pattern of the top-left and bottom-right sets, while the third flow pattern must contain the bottom-left and top-right sets.

Here's the critical point. Either way, the remaining two vector flow patterns must share the other four edges, namely:

+3 → -2, +4 → -1, -3 → +2, -4 → +1

And these four edges are parallel (Case #1). Thus, the remaining two vector flow patterns both contain one case #1 set and a second set which is the same for both. In other words, the remaining two sets are either both "double loops" or both "wickets". There are no other possibilities.

The three "double loop" case has already been covered, so let's flesh out the details of two "wickets" plus one "double loop", namely UD. One of these "wickets" must in some order contain the edges

(+3 → +1, +2 → +4) (-3 → -4, -2 → -1)

plus the four edges above shared with the other wicket. Inspection of Table 1 tells us that this is Uy (Dx):

+3 -2 -1 +4 +2 -3 -4 +1 +3

The other wicket must in some order contain

(+3 → +4, +2 → +1) (-3 → -1, -2 → -4)

plus the four edges above shared with the other wicket. Again inspection of Table 1 tells us that this is Ux (Dy):

+3 +4 -1 -3 +2 +1 -4 -2 +3

The order of the sequences is important, since by Rule #9, no two flows may point in the same direction along any given edge. Thus, for example, +3 → -2 in Uy must be matched with -2 → +3 in Ux, not with +3 → -2 in Dy, which flows in the opposite direction. Moreover, the flow order for the "double loop" UD is also determined, always in opposition to the flows of Uy and Ux.

+3 +1 +2 +4 +3 AND -3 -1 -2 -4 -3 $\bar{\mathrm{U}}\mathrm{D}$

Thus, the entire flow structure can be elegantly characterized by the three individual flows: Ux Uy $\bar{\mathrm{U}}\mathrm{D}$. If we reverse the flow direction, this same structure becomes Dy Dx $\mathrm{U}\bar{\mathrm{D}}$. But this is exactly the same pattern flipped over and rotated 90°. For this reason, the two wicket structures are amphichiral, unchanged through reflection. In fact, this same structure could be view from six different orientations, viz.

Ux Uy $\bar{\mathrm{U}}\mathrm{D}$	Fy Fz $\bar{\mathrm{F}}\mathrm{B}$	Rz Rx $\bar{\mathrm{R}}\mathrm{L}$
Dy Dx $\mathrm{U}\bar{\mathrm{D}}$	Bz By $\mathrm{F}\bar{\mathrm{B}}$	Lx Lz $\mathrm{R}\bar{\mathrm{L}}$

We can finally return to Lockyer's flow patterns. As just shown, there is really only one amphichiral flow structure (two "wickets" plus one "double loop"), but exactly three ways it can be implemented using the **EHS** system. That is, for any **EHS**, two will be wickets and the third a double loop, so the flow structure is characterized by the field that takes the double loop, or the odd man out. The three structures are $\bar{\mathbf{E}}\mathbf{HS}$, $\mathbf{E}\bar{\mathbf{H}}\mathbf{S}$ and $\mathbf{EH}\bar{\mathbf{S}}$, where the bar indicates the odd man out "double loop".

Viewing Fig. 1, which isn't entirely clear, I conclude that Lockyer makes the following connections:

$\bar{\mathbf{E}}\mathbf{HS}$: Muon Type Neutrino
$\mathbf{E}\bar{\mathbf{H}}\mathbf{S}$: Muon Type Anti-Neutrino
$\mathbf{EH}\bar{\mathbf{S}}$: Electron Type Neutrino

In his work, Lockyer notes that the Electron Type Neutrino is amphichiral, but does not say the same about the other two. Based on his naming convention, I infer that he believes $\bar{\mathbf{E}}\mathbf{HS}$ and $\mathbf{E}\bar{\mathbf{H}}\mathbf{S}$ to be mirror images of each other. This is not correct, since both of them are also amphichiral.

5. Conclusion

This paper confirms Lockyer's claim that only five possible flow patterns exist for the **EHS** system of vectors flowing around the edges of a cube according to the rules named in the introduction. Two of these patterns can be characterized as UDRLFB and $\overline{\mathrm{U}}\overline{\mathrm{D}}\overline{\mathrm{R}}\overline{\mathrm{L}}\overline{\mathrm{F}}\overline{\mathrm{B}}$, where no bar indicates a RH circulation around a face and a bar indicates a LH circulation. In effect, these characterizations say that either the flows travel CW around every face or CCW around every face. Lockyer associates these two flow systems with the positron and electron respectively.

The other three flow patterns manifest from two "wicket" flows having a common base (e.g. Ux and Uy), coupled with a "double loop" having the same base ($\overline{\mathrm{U}}\mathrm{D}$). One can visualize the two wickets as two hands cupped around the same face of the cube, but at 90° with each other. Though this flow pattern can be expressed with any of the six faces as a base, there is actually only one pattern, after reorienting. The three Lockyer patterns arise from the three choices (**E**, **H** or **S**) of odd man out, i.e. which of them has the "double loop" flow. Though this work confirms Lockyer's claim for three such flows, it contradicts the idea that two of them are mirror images of each other, since all three flow patterns are amphichiral.

I'd like to close this paper with a few words about applicability. Does it even make sense in physics to talk about any two of the EHS set flowing in exact opposite directions? Their cross product would be zero. For that matter, if any two of the three vectors, **E**-**H**-**S** , are parallel, the third must be zero, creating singularity issues. Moreover, what are we to make fo the fact that half the time $\mathbf{E}\times\mathbf{H}=+\mathbf{S}$ and the other half $\mathbf{E}\times\mathbf{H}=-\mathbf{S}$? This certainly creates challenges to orthodoxy, if not more.

Perhaps the cube idea needs an entirely different approach. Perhaps instead we need to think topologically. If a vector field (**E**, **H**, **S**, or something else) circulates, then a center or vortex exists for it. That is, we can find another circuit that is "inside" any given circuit, and continue moving further inside until we reach a null point in the field. But this "point" is really a line, because in 3D, fields actually flow as tubes, and our line represents the tube center. But if, like the torsion in the top of a wine bottle, the field reverses its flow direction, there must exist a point along our line where the reversal takes place. This point, perhaps having zero energy density, represents a topological defect in the field. One might ask, how many sorts of topological defects can possibly occur? Or how many different ways can three otherwise mutually orthogonal fields like EHS reverse themselves simultaneously? Perhaps Lockyer's cubes provide the answer. And perhaps topological defects are all that particles really are.

So though this paper challenges some of Lockyer's conclusions about the model and claims about the model as a representation of elementary particles, it cannot entirely dismiss the possibility that these models might indeed have something important to say about the structure of particles.

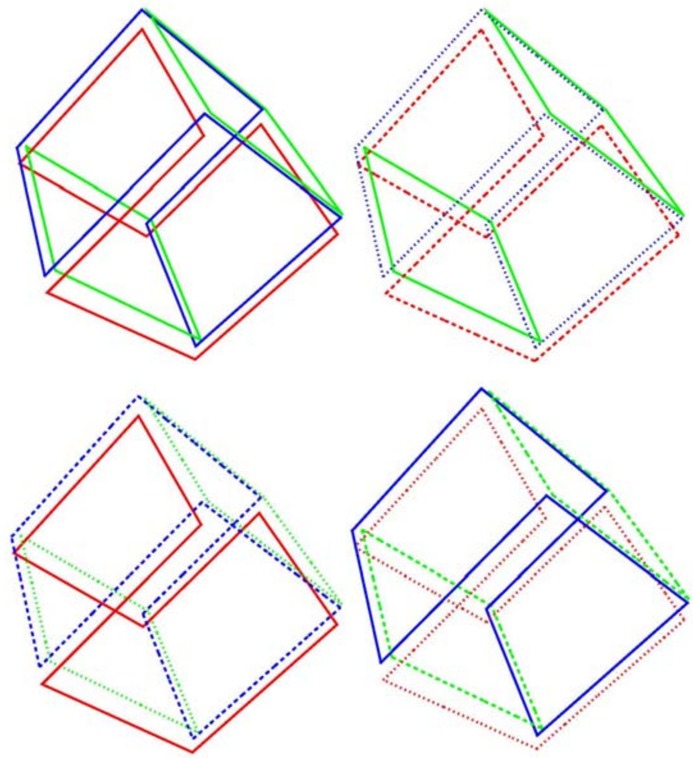

Fig 4. Lockyer cube flow patterns. The first highlights all three flow patterns, and the latter three each highlight only one. The top right highlights a "double loop", and the bottom two highlight "wickets" offset by 90° . (Created with Mathematica.)

References

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