Ideas for teachers

"Pity those who seek for shepherds, instead of longing for freedom!"

Paulo Coelho

In this document we suggest experiments and related discussions that are somehow aside main physical courses standards but according to us are fertile both in terms of possible practical applications as well as in terms of food for thought.

The following is a general survey of didactic materials that will be completed in the future by more specific documents according to your needs and feedbacks.

The non-radiative near-field devices and their associated proposed usages are situated at the turning point between mechanics and electromagnetism. It results that these devices are appropriate not only to illustrate the concept of resonance but also in the mechanical side the ideas of distant forces, corresponding work, and momentum conservation. In the electrical side, they are particularly appropriate to study situations where the current carried by moving charges is not conserved and where some displacement current should be considered. They are suitable to introduce the notion of self-capacitance and the even more puzzling one of intrinsic capacitance itself linked to new open circuit representations. Other fundamental notions of general electromagnetism can be easily studied such as, classical impedance, field impedance, and impedance tuning rules. Last but not least, they allow building new exciting distant (non-contact) sensors and heating devices as well as Wireless Power Transfer systems.

On the conceptual side, non-radiative near-field experiments allow the student to get in direct touch with some fundamental issues arising in theoretical physics. For instance the teacher may explain why the photon box is not an appropriate underlying model for the capacitor (for instance photons collisions should arise on the outside side of electrodes to generate the proper forces). As a result, EM near-fields cannot be considered in the same frame as Maxwell-Boltzmann statistics where atoms or molecules would simply be replaced by photons. Ultimately electric and magnetic fields cannot, in general, be associated to some classical photon's flow as an oversimplified interpretation of QED falsely suggests. Showing our young fellows the tangible limits of our own knowledge is probably the best way to get them sincerely involved.

In a few words, non-radiating near-fields give the perfect playing-yard for future engineers or researchers as it embraces through simple empirical approaches and/or the realization of exciting devices all quantities and concepts involved in mechanics, electricity and general electromagnetism (apart from propagation and waves). Non-radiating near-fields give also tangible starting points to discuss some of the deepest issues modern physics is facing.

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A - Single dipole thematic and related applications

Resonance

Resonance is a very general process that is involved in many fields. Resonance arises every time energy, or whatever extensive quantity, oscillates through reversible transformation in a dual quantity instead of being totally lost at each alternation (for instance potential energy/kinetic energy). The device involving the two oscillating dual aspects is called a resonator. Usually the balance between the dual forms of the quantity is only obtained at a specific frequency or a set of specific frequencies. In a perfect lossless case, even if only a small amount of the quantity is injected in each new alternation, the amplitude of the oscillations will increase infinitely. In real systems some dissipative or destructive processes always bound the amplitude to some value. When a stable permanent regime exists, the ratio of the quantity oscillating compared to the quantity loss in one cycle is called the quality factor of the resonator.

Our High-Quality resonators are of magnetic type and electric type. In both cases energy oscillates at resonance in equal amounts between an electric form and a magnetic form. The two types differ only by the storage locations of the two forms of energy.
For the magnetic (induction) type, the energy is stored externally in a magnetic form providing the possibility of inductive interactions with the surrounding medium or other similar resonators tuned to the same frequency (see following chapters for more details); the electrical energy is stored inside a capacitor.
The electrical (capacitive) dipole is the electric counterpart (dual), it involves an electrical field that stores energy externally providing the possibilities of general capacitive interactions, and an inductor with a ferrite core to store the magnetic energy internally.

Possible measurements

In both cases (inductive or capacitive dipoles) it is possible to measure the frequency response and to determine the Quality factor according to different methods (bandwidth method or overvoltage method for instance).
It is also possible to show that if one takes into account the stray capacitance of the coils the two methods do not converge to exactly the same values. For advanced student the measurement of resonance and anti-resonance frequencies may be used to determine empirically the stray capacitance of the coils.
Concerning general measurements, it is possible to show that if an usual probe does not affect the magnetic resonator because in this case low impedances are involved, it affects a lot the capacitive resonator that is characterized by large impedance values (typical capacitance of the electrode array are in the 2.5pF range). If you are not equipped with a very low capacitance probe you may avoid this issue by placing the probe tip at some distance from the high-voltage electrode (say a few centimeters). In such a case you will realize a bridge divider with a very small input capacitance. As you do not know the value of this capacitance, only relative measurements are possible. This allows to make overvoltage and bandwidth measurements. It is

important to protect the probe type and to insure that the distance between the probe and the electrode doesn't vary during the measurement process.
Equivalently you may sense the magnetic field at some distance without perturbing the resonator using a few turns of copper wires connected between the probe tip and the probe ground. Note that this sensing technique is available provides the working frequency is much smaller than self-resonance frequency of the sensing coil.

Related ideas & complementary themes

You may insist on the fact that the resonance frequency corresponds to situations where the two forms of energy are equal in amounts and the two fields are in quadrature phase. The correspondence with the mechanical pendulum is straightforward; the magnetic energy is similar to the kinetic energy and the electric energy similar to the potential energy of gravity forces or compression forces for springs.

An interesting discussion may be raised about the existence of two similar types of mechanical resonators that could be associated to the dual types of EM resonators. This will enable you to introduce the idea of the problematic localization of energy: In Maxwell frame, any arbitrary rotational field can be added to the Poynting vector without changing the energy balance. In classical as well as in quantum electrodynamics, energy density as well as energy flux are not defined locally only the global balance has some meaning.

For the most advanced students, you may also discuss the "mechanical" nature of electromagnetic fields. You may for instance introduce the Einstein, Cartan and finally Hermann Weyl's attempts to unify EM and gravitation fields through the idea of "torsions" of the space-time working in parallel with the "curvature" of the classical general relativity, see for instance: "*Raum-Zeit-Materie and a General Introduction to his Scientific Work..pp 313-314"*.

See the conceptual issues themes below for more mind-boggling subjects.

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Reactive power, up & down converters

Reactive power

The sine waves measurements on resonant circuits, allows introducing the distinction between the transferred or lost energy and the oscillating energy that remains stored in the circuit without being used or lost. It is then easy to define corresponding powers and their respective units, Watts (W) for dissipated or transferred power and Volt-Ampere (VA) for reactive power. It is easy to show that in case of large reactive power levels, for the same effective power extraction, the dissipation is proportional to the reactive power level, and more generally; the lower the reactive power level the lower the losses.

For a starting experiment, student may realize a basic serial LCR circuit (connecting the resistance to the ground simplifies measurements). They may then measure input and output power according to the various values of the load and compute power loss and efficiency relative to either reactive power level or load resistance value.
Note that in order to measure input power and to be sure that the frequency is tuned at resonance the simplest way is to set an appropriate resistance in series with the generator and to visualize the signals before and after the resistor; if the two signal are in phase the input impedance is resistive and calculation of input power follows straightforwardly.

Up converter measurements

Similar measures can be made with a load connected in parallel with either the coil or the capacitor of the serial LC resonant circuit. In this case student may have to find the frequency that leads to a resistive behavior at the input side (using the same serial resistor idea). They will be allowed to show that this frequency is slightly different according to resistive load values. They may also measure the voltage gain of the system according to the resistance value and to show that the maximum gain is equal to the quality factor of the coil (provides the stray capacitance of the coil is negligible compared to the serial capacitance. They could be also asked to show that efficiency depends on the expected voltage gain.

Down converter measurements

A down converter structure is obtained by simply reverting input and output ports.
Similar measurements can be made (finding the frequency tuning for a resistive input, measuring efficiency according to voltage ratio).

A subsidiary question could be to observe the behavior when the input signal is replaced by a square signal instead of a sine-wave signal for the various possibilities (the two tank circuits, the two up converter implementations and the two down converter implementations).

Note that our HQ inductance KTL-IC1 and our HQ inductive dipole kit KTL-IK1 are perfectly appropriate for such experiments. Their extremely high Q-factors, allowed very large reactive power levels. Besides they have a very good thermal stability. They enable very accurate measurements in a very wide range of situations.

Reactive near-field with high or low impedance

Up to here, all proposed experiments have been based in the classical circuit frame where components behave like black boxes with particularly simple behaviors. Let's turn now to application where external electric or magnetic fields are more directly involved.

Measuring external fields

The first question is: how can we measure such external fields?

They are many ways that can be used to measure the magnetic field. For instance one might use Hall sensors or any winded sensor, however most are not be able to measure alternating fields at quite large frequencies. The simplest and low cost way according to us is to use a small air coil made of a few turns of large copper wire and to connect it to a usual oscilloscope probe. However, before to use your probe you must verify that the self resonant frequency of your coil is well higher than the frequencies you are going to work with. Note that for most measurements you do not have to calibrate your probe as absolute measurements of magnetic field are not necessary in the following proposed investigations. Note that the sensing coil should be very flat in order to be insensitive to the electric field (see the remark below concerning solenoid fields).

Measuring the electric field is somehow harder; however as quasi-static condition applies for the field, the electric field can be derived from a scalar potential. As a result, one as to find a way to measure the potential in every point of space surrounding the device investigated. This is still an issue as any conductive material placed in the vicinity of the structure will modify the electric field lines.
Besides usual probes will not allow direct measurements of electrode voltage has in most cases the probe capacitance is much higher the self-capacitances of the electrodes (it is not even sure that the probe or the oscilloscope input circuit will not be destroyed by large voltages arising near resonance). It must be said that there is absolutely no risk for the experimenter as his own body has a very low impedance and the electrode voltage will drop down well before he even touches the electrodes. In spite of these difficulties it is possible to obtain a rough idea of the electrical field lines distribution using a simple probe protected by a plastic tips to avoid direct contact with electrodes. Note that our KTL-PB1 probe allows accurate direct measurements of electrodes voltage as the probe impedance is very low (0.5pF) and its maximum peak voltage very high ($>10kV_{pp}$). Such a probe will enable not only to obtain the electric field line repartition but also to derive correct absolute values for the electric field amplitude.

Picturing field lines

With the appropriate tools, it will be possible do obtain the general profile of field lines in both dipole cases. The student will then observe that, if at some distance the field lines are very similar (see for instance: Electric dipole moment & Magnetic dipole moment), they are very different at short distances. In the electric case the field lines ends on electrodes whereas the magnetic field lines form closed loops.

Note that for our inductive dipole, it is possible to measure both electric and magnetic field lines, as for solenoid coils at resonance there is a large voltage difference between the two ends of the coils. As a result both dipoles fields are somehow superposed in this case. Our coil is provided in our other inductive products KTL-IK1& KTL-ID1 with a capacitor that is much larger than the stray capacitance of the coil. As a result the energy stored in the electric field is much smaller than the one stored in the magnetic field. In other words, the capacitive dipole effects can be neglected in most cases (In a short future we will discuss interesting mixed coupling experiments).

Field impedance concepts

The impedance concept Z=U/I can be generalized to the fields. The starting point is simply to notice that the voltage difference is proportional to the electric field **E** and the induced current is proportional to the magnetic induction **H**. It could then be tempting to define the field impedance has Z=E/H. However **E** and **H** are vectors made of complex numbers in the general frame, it results that many different definitions are generally possible. At large distances from the sources, the two fields are perpendicular so the simplest definitions for the field impedance are: $Z_E=E_{Par}/H_{Trans}$ and $Z_M=E_{Trans}/H_{Par}$ but they can be regrouped in a single one if a conventional orientation common for the two types of dipoles is defined.
However, in near field situation the picture is blurred as the two vectors have at least two components to account for. This field impedance can be also defined in situation where both fields are parallel but in this case the quantity is no more related to the far field one (which is for a plane wave in vacuum real and equal to Z=377Ω), showing clearly that some kind of fundamental transition occurs between near and far fields.

Some general properties can be quite easily derived through measurements:

1 In non-radiative near-field situations, the two fields are in quadrature phase in the whole domain involved, the total energy radiated far away is much smaller than the reactive energy involved in the near-field.
2 In ideal capacitive situations the field impedance values are larger than the classical wave impedance.
3 In ideal inductive situations the field impedance values are smaller than the classical wave impedance.
4 Some particular situations of superposition exist that do not give birth to large radiated field, but in such cases the definition of field impedance is more problematic.

Kantan Labs provides tools and explanations to enlighten all these properties. For instance most of the previous properties can be investigated using our KTL-IK1 kit and the previously described sensing techniques.

Some simple dipole-environment interactions (application to distant sensing, heating)

In this chapter the student will start considering energy transfer at some distance, so he will be faced to simple distant interactions. However, in this preliminary step toward wireless power transfer technologies, we will consider that the element that interacts with the dipole is the whole external medium or a part of the external medium that behaves in a non selective manner (are made of simple non resonant elements).

Two classes of applications could be defined: sensors and power transfer devices.

For sensors the modifications of the environment or a part of the environment will lead to measurable changes in the electrical circuit characteristics. These characteristics are variations of the resonance frequency or variations of the quality factor or some special combinations of the two quantities. Applications range from measurements of complex permittivity or permeability (the absolute values and their associated dissipation factors) to the sensing of small non homogenous regions. The magnetic sensors applications are well known (for instance for treasure hunt), electric sensors could be used to detect for instance bubbles, other non homogenous regions or any conductive material present in a nearby dielectric material.

For power transfer device the coupling is used to transfer energy in selected places. In the simplest implementations the energy transferred is directly transformed into heat but many other possibilities can be investigated electrochemical energy transfer, heat pumps using Peltier's effect…

The high Q-factors of our circuits enable to realize efficient power transfer or very efficient sensors even if the majority of field lines do not even cross the part of the environment you are interested in. This is due to the ability for resonant circuits to recycle untransferred energy. However you must be careful in the interpretation of the resonance effect. Many engineers and even some researchers falsely believe that resonance increases the coupling coefficient. This is absolutely false; the coupling coefficient as usually defined is a constant value that depends on geometric properties of the link but in most medium not at all on frequency. For the same amount of energy involved in the source circuit; always the same amount of energy will be transferred to the distant element. However for the same input power, if untransferred energy is recycled the amplitude of the generated field will increase a lot compare to a situation where untransferred energy is lost, as a result a much larger energy will be transferred to the final destination. The overall performance often involves the product kQ, as this quantity is the product of the coupling due to the link and to a special performance due to the device; it is sometimes called "factor or merit", but for historical reasons we prefer to call it "coupling index".

Distant sensing implementations

Many interesting implementation are possible and many remain to be discovered.

A very simple qualitative experiment is to show that a magnetic dipole is very sensitive to ferroelectric materials and to a smaller extent to any conductive materials. In the first case a large frequency shift for the resonance is observed whereas in the second case the quality factor is mainly affected by the losses due to induced currents. A simple electronic circuit will enable to discriminate ferrous conductors to non-ferrous conductors.

For electric dipoles it is possible to show that they are strongly affected by any conductive grounded bodies but very little affected by floating conductor specially if the conductor shapes follows the equipotential surfaces. It is also possible to show that the resonance frequency will shift if a dielectric material is placed near electrodes and that the quality factor is reduced if this material has a large loss angle.

Distant heating applications

Heating some metallic material through an induction coil is well known. Our KTL-IK1 resonator is able to handle very large reactive power (in the 10kVA range), applications able to transfer efficiently a few tens of watts even in for coupling coefficient in the 1% range are allowed by the very large quality factor of the coil.

Heating some dielectric material with our capacitive dipole is also possible but requires some abilities has the coil could be damaged in case of overvoltage. However a skilled experimenter can use our KTL-I1 coil combined to an appropriate electrode system to reach larger voltages and reactive power levels and produce higher dielectric heating possibilities.

B - Multi-dipole thematic & related applications

The idea of coupling in a global interaction's frame

The use of several dipoles enables to illustrate the interaction concept, and related themes.
The first notion that can be illustrated is the idea of coupling coefficient. The teacher may then explain the general idea and may suggest some practical definitions for the coupling coefficient. It is often necessary to take time to explain and illustrate the differences between the notion of coupling and the notion of efficiency. Our products are particularly appropriate to do so as it is easy to measure large efficiencies even in very small coupling conditions. If enough time is available the student may for instance find how the coupling coefficient decreases with distance, how efficiency behaves according to distances but also tuning conditions, and how to derive general rules and formulas for the best tuning conditions according to the quantity to be optimized (power level or efficiency). This analysis will show more clearly how the various quantities Quality factor, coupling coefficient and efficiency are related.

An interesting idea is for instance to show that two identical coupled oscillators behaves as their electron constituents, following the Fermi-Dirac statistics: If you take two identical resonators; at large distance they resonate at the same frequency (with the same energy level) and if they get closer, two modes emerged (the degeneracy is removed) and you may consider that each dipole has a different energy level. Of course it's a simplistic analogy but it may help to introduce such abstract quantum properties.

The fundamental differences between non-radiative coupling and classical far-field coupling through waves

Analysis can be pushed further; according to measurements proposed previously it can be shown that the interaction takes a quadratic aspect regarding the coupling coefficient or the oscillating amounts of energy on both sides, only in case of small couplings. However in case of larger coupling the interaction is no more quadratic and depends a lot on the near-field structure. This is easy to understand considering energies; in a small coupling situation only a small fraction of the energy involved in the source is transferred to the load, in return an even smaller effect of the energy oscillating in the load bounce back to the source; said abruptly the source doesn't see the load. As a result it is possible to separate the load from the source and to treat separately the generating process and the receiving one. In higher coupling situations the load presence will directly perturb the source according to their respective distances, shapes, impedance. In such a case only global results matter, the knowledge of the field on a point or even on a surface is for instance little help to compute the total amount of transferred energy. Simultaneously it is not even possible to measure the field without perturbing what is measured. In near-field situations, specific laws and principles apply; for instance in the circuit frame it is not possible to consider that energy goes progressively trough various elements form source to destination, the localization of energy as even no meaning, the circuit must considered as a whole, any component modification having a global impact on the circuit's behavior.

Wireless power transfer & Impedance tuning considerations

Our versatile devices enable to derive accurately from experiments both the frequency tuning rules and the best resistance tuning according to what parameter should be optimized (power or efficiency). Such studies will enable to introduce the importance of the coupling index (the factor of merit) and the generally slight differences that exist according to situations (serial resonant, parallel resonant, serial parallel resonant for both electric and magnetic coupling cases).

Transition towards propagation in case of a chain of couplings

It is also possible to study the behavior of a chain of coupled resonators placed along a given path. This will allow showing how energy can be guided towards remote areas. Beside it will be easy to demonstrate that after a small amount of resonators placed in cascade, the best tuning condition doesn't differ from impedance tuning for propagation lines, and how intermediate resonator presents equivalent resistive impedance. This is possible even if the describing model is still based on quasi-static rules that do not involve propagation at all (the wavelength will still be much larger than the device size). In other words studying a chain of electromagnetic resonator, as for a chain of mechanical oscillators, is a simple way to introduce progressively propagation concepts.

C - Conceptual issues that can be discussed

How modern physics conceptually accounts for the reversible energy storage in external fields surrounding quasi-static devices?

According to only Maxwell equations, energy density as well as energy flow is not defined locally. The classical definition of the Poynting vector and the energy density are only possible options among many others. Any constant value could be added to the energy density as well as any arbitrary rotational field for the Poynting vector.

In QED also the localization of the EM energy is undefined. As EM energy vector is the photon it result that the photon has no defined trajectory in space; it only has a probability to be emitted in some place and to be absorbed in another one.

If energy is not defined locally it means that according to the equivalence principle mass also is not. As a result the present position is to consider the mass of a particle to be an associated number, like the charge, the spin without any reference to a spatial distribution.

However the doubt concerning energy localization is removed in special and general relativity as only the current definition of the Poynting vector is allowed to be an invariant of the theory.

As a result if we don't know the exact repartition of the mass of the electron, if any, it is clear that this mass follows the electron and is not stored at the other end of the galaxy. Same result applies for photons; if the trajectory of a single photon has no meaning in QED, the trajectory of a beam of light is clearly defined at the macroscopic level.

So what about this strange quasi-static storage of energy around non-radiating devices? To some extent it is possible to wonder if near-field observations do not advocates for an extended model for particles (see below for more details).

How can we take into account the dazzling punctual aspect of the electron's charge and the infinite extension of the static field associated to it?

First the teacher should verify that the student understands the two core ideas:
On one hand the electron particle could be conceived as perfectly punctual as no experiments even high energy collisions have brought any evidences of any substructure. If such a substructure exists (for instance as depicted by string theories), according to the last high-energy investigations, it must be smaller than at least 2.10^{-20}m.

On the other hand, the electric field associated to the electron at rest decreases monotonically quite quickly with distance but occupies theoretically to some extent the whole universe. As contact forces are due to electrostatic repulsion forces, two electrons alone and at rest in the vacuum are in contact whatever the separating distance. When helped by resonances (to avoid large leakage of energy) such contact forces can be used over distances much larger than the devices' sizes.

The present paradigm is to consider the punctual charge and the field as two separate entities. However, treating near-field in the same frame as the far field (waves), as done in EDQ, doesn't bring any new conceptual breakthrough and leads to very complex mathematic developments involving strange virtual scalar and longitudinal photons (see for instance Claude Cohen Tannoudji, Introduction to Quantum Electrodynamics p.XVI). As stated by P. A. M. Dirac, the aim of QED is "not so much to get a model of the electron as to get a simple scheme of equations which can be used to calculate all the results that can be obtained from experiment."

The other possible paradigm is to consider that the electron is made of (and possibly only of) its static field. This approach leads to a classical electron radius of $2.5\ 10^{-15}$m. This paradigm was devised in the past by some scientists such as Max Abraham, H. A. Lorentz., and still have modern defenders, but it also leads to many difficulties (the basic ideas of a solid charged sphere as well as any simple distribution of spinning charge don't work; the best idea is probably to imagine an inside singularity of some sort),….the discussion is open, may be an appropriate conclusion is that both approaches are not totally satisfying yet.

The QED approach works well in some cases but is conceptually empty and then inappropriate as a physical representation of the real world. The classical approaches are very comfortable for the mind as representation of the surrounding world but leads to false predictions or no predictions at all and so cannot even be considered as theories yet but only as pure conjectures.

For more see for instance: Models of the electron

For advanced student you may also discuss some false possible interpretations, for instance the idea of the electron with a large evanescent size doesn't mean the electron can interact instantaneously with other distant charges. This idea of an instantaneous scalar potential leading to non-delayed interactions, you may find in some documents or fringe web sites, came from a bad interpretation of the gauge freedom. In the Coulomb's gauge, the scalar potential follows instantaneously the charge movement validating to some extent the idea of an extended electron.

However the vector potential doesn't respond instantaneously to current variations. Besides only the combinations of the derivatives of the potentials enable to compute the electric and magnetic fields. Whatever the choice of the gauge, the observable results (the fields) will be the same: they will propagate in cases propagation has to be taken into account. To explain a little more this last point: fields always propagates to some extent but in some cases propagation is not a necessary concept to account for. For instance in a capacitor you do not need to consider that the electric field arises on one electrode first and propagates towards the opposite one.

What is the Mach's principle?

The idea is that distant masses in the universe structure in a way our local frame. Mach's demonstration of such a concept was based on the existence of an absolute frame for rotations: Imagine an experimenter in a totally opaque box lost in the middle of our universe far from any celestial body. If according to the relativity principle he is not able to measure his own speed relative to any of other body in the universe, he is however capable using simple tools to know when he is spinning or not. If he is able to find a frame that is not revolving and start to look outside he will find that it corresponds also to the frame where far stars are also not spinning relative to him. The simplest possible interpretation is: some form of physical relation between the experimenter local frame and the universe global one has to exist.

A possible explanation is linked to the previous topic: "Two electrons at rest in the vacuum are in contact whatever the separating distance". The effect and practical range of such an electrostatic force increases as the number of electrons is increased. For electrostatic forces these effect are however restrained to quite small ranges as a perfect balance between negative and electric charges is observed all around and it involve large amounts of energy to separate many charges far apart. For gravity forces all effects cumulates as now negative mass seems to exist. If we were in some edge of the universe (if existing) we would be strongly attracted toward its interior. If we assume that the universe is infinite or if we are right in the middle of it, the attracting forces will globally cancel but we may also imagine that they tends to tear apart our local space.

Mach's principle somehow advocates the existence of a substrate whose local rules depends on global constraints as it is the case in a fluid for quantities like pressure and temperature.

The general relativity is a global theory compatible with Mach's principle. Note that you may also discuss with your student the idea that black energy could be linked to the tearing apart process. More generally some physicists assume that the global energy of the universe could be zero as gravitation energy is negative and may compensate exactly the positive energy contained in matter. The idea of a free lunch universe (the whole universe has a zero energy cost) was first proposed by Edward P. Tryon in 1973 (surprisingly late as this idea could have emerged just after the birth of the general relativity).

What are the differences between local and global models in physics?

Local models are mathematical analysis of idealized situation that can be totally disconnected to the rest of the world. For instance if you study the collision between two solid balls in the vacuum (two-body problem) you need to know only the two initial velocities and the respective mass and sizes (if your model accounts for solid collisions) of the two bodies.

For global models the interactions with the rest of the world have to be taken in a more complex manner but still idealized in some ways. For instance if you want to know how a liquid flows in a pipe you will have to describe accurately the input flow (for instance through the flow profile, the degree of turbulence,…) as well as the characteristics of the pipe material, porosity, state of surfaces, and finally the output conditions (for instance the output flow comes out in a totally open space at a given static pressure). These conditions are known as "boundary conditions", the problem will be treated by using the boundary conditions combined to some general laws that involve at some level these boundary conditions.

These two types of models are appropriate for different types of situations, the local models are appropriate for collisions and some case of propagation (for instance propagation of local perturbations in open air). The global models are somehow complementary as they admit simple analytical solutions only in the case where propagation can be neglected.

For the last century local models have taken a central place in theoretical physics as they fit well for punctual particle interaction models and can be extended to large numbers only using averaging and statistics.

For instance the two models (the global treatment of a continuous medium and the local statistic approach) match well to describe the evolution of a large number of gaz atoms or molecules at quite low pressure (when binary collision predominates), in such a case the Maxwell-Boltzmann statistics through the BBGKY hierarchy and appropriate closing conditions enable to retrieve the Navier-Stokes equations with appropriate values for the coefficients. Some good approximations are obtained at higher pressures using perturbation methods, but such methods do not converge at very large pressure or for liquids. The same difficulty arises to obtain the general relativity equations for space-time evolution from any statistical model of local interactions.

To summarize, continuous medium physics requires global approaches to treat most problems. Only far-field problem could be treated efficiently in local frames. The standard model is based on one side on a global theory to describe gravitation field and on the other side on local theories to describe all the other interactions. The electromagnetic near-field domain is a proper frame to illustrate these difficulties.

How can the vacuum/space-time be simultaneously nothing and the source of everything?

This topic enable to introduce how the space-time has shift from a static mathematical frame in Newton's mind to a physical object that is distorted by the presence of masses in Einstein mind. In parallel in Quantum theories the vacuum as progressively shifted from an empty static place to a very dynamic place invaded by large amounts of virtual particles (even in infinite quantities). If both leads to the same idea of an underlying substratum the two conceptions haven't reached a unified status yet.

How the idea of ether has evolved in the past to finally disappear from the list of relevant stuffs?

The idea of a distant action using no substrate was difficult to admit to most researchers (and still is to some of them). When Maxwell discovered the possibility of waves, he naturally assumed that these waves like other known waves should propagate inside on or the surface of a given material substrate. As it became soon clear that they were able to propagate even in the vacuum, this original substrate shifted to something with material properties but containing no usual matter that was called "Ether". As various experiments to measure the speed of the earth relative to this Ether failed, this substrate became even more immaterial.
In order to explain the special relativity concepts Einstein was often disturbed by questions on the importance of Ether and eventually convinced his contemporaries that Ether was not a relevant concept to understand his theory.
Soon after the discovery of the quantification of EM emissions by atoms and the explanation of the photoelectric effect by photons, the idea that EM energy was carried by particles crossing a totally empty frame emerged. Even if the vacuum status has fundamentally evolved in quantum theories, this idea is still very pregnant in modern physics. When Einstein came up with his general relativity theory, he realized that the space-time was no more the mathematical passive frame but was a physical object described by his theory. He then decided to reintroduce the idea of Ether but with a new name: "Substratum". However Einstein was not followed, to be honest only a few present physicists realize that general relativity implies a profound change in the space-time/vacuum status.