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What surfaces in the operation of noble liquids dark matter detectors

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What surfaces in the operation of noble liquids dark matter detectors

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ABSTRACT: Though noble elements dual-phase detectors have long application history in dark matter searches, some uncertainties and differences in backgrounds still persist. We compare effects caused by unextracted electrons on the liquid-gas interface in Xe and Ar detectors with a large family of effects at the liquid helium surface. We pose that electron and ions accumulation on the liquid surface in detectors can lead to the formation of ordered surface states, charged liquid surface instabilities in an electric field, electrospraying, interactions with surface waves, and other effects. Not only delayed electron emission signals can be generated, but the extraction efficiency for electrons produced below the liquid surface can be altered by the presence of surface charges. Several factors lead to surface electron accumulation, and effects became bigger with the increase of the detector size. We discuss possible experiments to reveal surface electron effects and design changes to alleviate electron accumulation. We conclude that studies of these effects are desirable prior to making final design decisions for the new multi-ton liquid Xe dark matter detector projects like DARWIN, XLZD, and large Ar dual-phase detectors.

KEYWORDS: Dark matter particle detectors, noble liquid, nuclear recoils, excess background, electron extraction, surface electrons, Wigner crystallization, dimple crystal, capillary, and gravity waves, charged liquid surface instability, electrospraying.

Contents

1. Introduction

Over the last 20 years, the community has continuously increased the liquid mass of dual-phase dark matter particle detectors from 10 kg in the Xenon10 detector [1] to about 7 tons in the LZ experiment [2]. Building experiments with up to 30-100 tons liquid Xenon targets- like the DARWIN [3] project- are now under discussion.

Fast and unimpeded transport of electrons and photons without diverting energy for chemical reactions, long-living excitations, trapping, and delayed releases of energy and charges allows multiple detector applications of noble elements. In dual-phase detectors, photon detector arrays detect the scintillation pulse S1 produced in liquid by the energetic particle. Free electrons produced by the primary particle move in the applied electric field to the liquid surface, escape into gas and generate electroluminescence pulse S2. Each electron extracted into gas produces multiple photons (gas amplification) allowing single-electron detection and better energy resolution (electron number resolution) than measurements of small current pulses. Low energy detection threshold, electron and nuclear recoil discrimination by the ratio of S1/S2 pulses, and scalability to sizeable liquid target mass make this technology of choice for direct dark matter particle searches.

At the same time, the origin of the excess in few-electron events (1,2,3,…,8), differences in observed low-energy events spectra, and the appearance of significantly delayed multiple electron emission events (e-bursts) after muons and other large ionization events in some detectors like Xe10 [1], LUX [4]. are not well understood.

This paper compares the accumulation of unextracted electrons on the liquid-gas interface in different detectors: what differences we see, what impedes the escape of unextracted electrons on the liquid surface to the walls of the detector, and discuss what other effects electron accumulation can have on the detector operation.

We briefly mention the effects known for liquid helium surface: formation of ordered electron states like Wigner crystal and multi-electron dimple lattice, charged liquid instability in a strong electric field, electro-spraying-like effects, and interactions with surface waves. The appearance of ordered surface states can explain differences in unextracted electron behavior in detectors, and why electron bursts in some detectors can occur at the exact position of the previous S2 event with a large time delay. We also discuss the possibility that the accumulation of

unextracted electrons on the surface can suppress the extraction of small electron signals originating below the liquid surface.
There are more features of the electron extraction process and delayed electron emission in detectors that have no clear explanation yet. The effects we discuss in this paper can lead to misinterpretations and wrong conclusions about particle physics, but the presence of these effects can be checked and accounted for by condensed matter-style experiments with a small detector set-up. We believe that through systematic studies of material and condensed-matter effects, we will come to a better understanding detector's operation and resolve the problem with annoying excess backgrounds in noble liquid [5] and solid-state [6] dark matter particle detectors.

2. Dwelling time of unextracted electrons on the liquid surface

Electron is attracted to dielectric fluid due to fluid polarization. The kinetic energy of a free electron moving in a liquid under an applied electric field must be above ~0.85 eV for the electron to escape from liquid Xe and above ~0.65 eV for the liquid Ar; see, for example, [7,8]. A free electron drifts in noble liquids like Ar, Kr, and Xe under an applied electric field can be described as chaotic motion with multiple changes of direction in collision events [7,8]. If a field-driven electron loses kinetic energy near the liquid surface, it will not escape and stay on the liquid-gas boundary.
We need to make a distinction between free surface electrons which presumably have large surface mobility and negative atomic and molecular ions which also can be trapped on the liquid surface but will have low surface mobility. When free surface electrons stay at the surface sufficiently long, they have a chance to be trapped by electronegative impurities and form low-mobility negative ions. Unfortunately, we do not know publications where surface mobilities of free surface electrons and surface ions were determined, nor any data on the lifetime of the free surface electron before trapping by electronegative impurity.

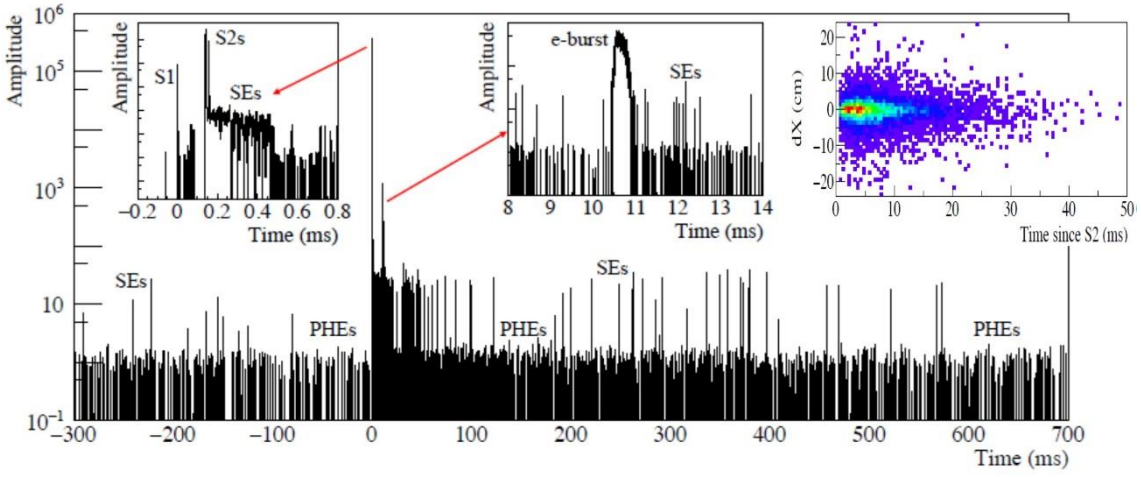


Figure 1. A continuous LUX waveform over one second (from [4]). With only one 2.3 MeV gamma interacts with detector, southlands delayed background electrons and photons were observed following S1 and S2 pulses. Left and central inserts show zoomed S1-S2 event window and delayed e-burst events and random single electrons (SE) and photoelectrons (PHE) pulses. The right insert is the X position difference between e-bursts and preceding S2 as a function of time delay (only events with no additional S2 pulses during [-30,+50} ms relative to S2 were taken)

Negative ions cannot gain considerable kinetic energy when drifting in an electric field in liquid, but their short-range interaction with neutral noble elements atoms (Xe, Ar) can be repulsive [9], and we cannot exclude the possibility of a lower energy barrier for extraction of negative ion into a gas (than the barrier for free electron extraction) in the presence of extraction field and high surface concentration of surface negative charges.
Electrons and negative ions trapped at the liquid-gas interphase can drift away to the detector's metal walls or be extracted into the gas by some processes.
One type of process - e-bursts- is a delayed escape event of a significant number of electrons. It may include the escape of negative ions with subsequent liberation of electrons in ion-gas atoms collisions. E-bursts were observed in Xenon 10 [1] and later in other detectors, and recently studied in detail in the LUX detector [4]. Notably, in the LUX detector, e-burst appeared at the exact X-Y coordinates where previous significant S2 events (electron extraction) took place with delays up to 50 ms (see Fig.1); several e-burst were possible at the same location [4]. Thus, unextracted electrons can stay at the liquid surface for up to 50 ms (or more, no longer data were analyzed) in LUX without drifting from the "origin" X-Y position.
The RED1 (Russian Emission Detector) [10], ZEPLIN III [11], and RED100 [12] detectors have no E-bursts. These detectors also have a common design detail: the anode grid in gas is attached to a metal ring holder which is touching the liquid surface, see Fig.2. The published electric field pattern calculated for the ZePLIN III detector [11] demonstrates an electric field component tangential to the liquid surface near the active area's perimeter (see fig.3), which will sweep surface-bound electrons or ions nearing the perimeter area toward the metal anode support ring. While E-bursts are not present in these detectors, the paper [6] describes intense light emission pulses (S3 pulses) at the perimeter of the RED1 detector following muons or other significant ionization events.

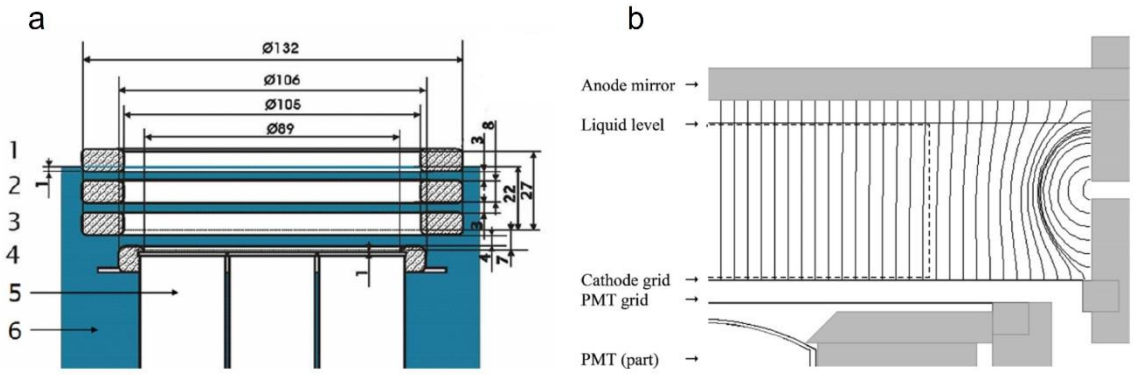


Figure 2. Left-electrode system in RED1 detector [10]: 1-first electrode ring and aluminum-coat stainless still mirror on it; 2-intermediate field-shaping ring; 3-third electrode ring with mesh cathode (stainless still); 4- electrode ring with screening grid (stainless still); 5-PMTs; 6- LIQUID Xe; all dimensions in mm.
Right- enlarge fragment of ZEPLINIII design [11] (RED1 was a prototype for ZEPLIN III) with calculated electron trajectories close to the field-shaping electrodes; the dashed line shows the boundary of the fiducial volume; at the perimeter of the detector field component tangential to the liquid surface is pushing surface charges toward the metal electrode.

For muon events in the RED1 detector [8], the authors separated the time between S2 and S3 events into shorter intervals and calculated the position of light production (center of gravity) for each interval. The light production was moving along a straight line connecting the S2 and

S3 locations, indicating the presence of some electron emission mechanism different from e-bursts or S3 events. S3 pulses were present when the liquid level in the detector was slightly below the anode support ring [13]. So, the S3 light pulses originated in the strong electric field region in a thin gas layer between the charged liquid surface and the metal anode support ring. As one can see from Fig. 2, the grid holders design was slightly changed in the ZEPLIN III detector relative to the RED1 detector– likely to avoid accidental separation of the anode holder ring from the liquid surface (The RED1 was a prototype for ZEPLIN III).

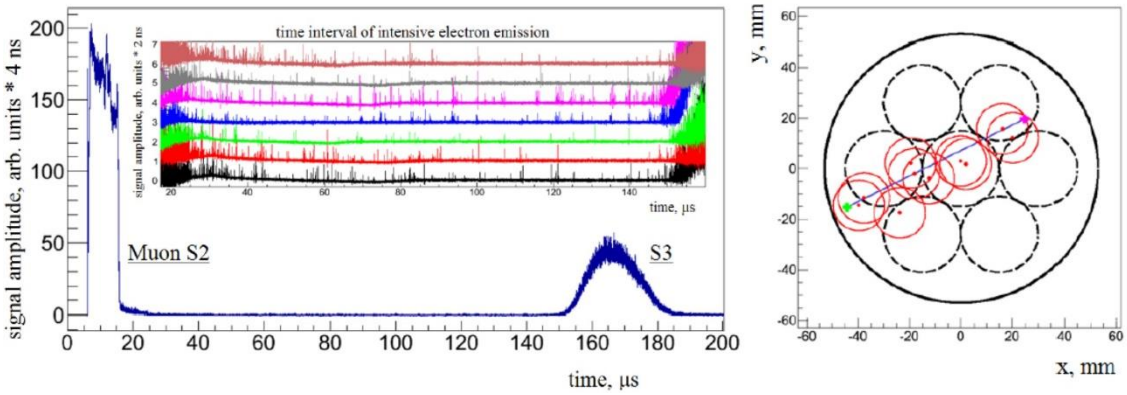


Figure 3. Left- Example of events containing a muon S2 signal and the following S3, the sum of waveforms in all seven PMTs in RED1 [10]. On insert-individual PMT waveforms between S2 and S3 events with electron emission signals during this period; S2 is essentially distorted due to saturation. Right- reconstruction of the spatiotemporal image of the muon event, perfection onto a horizontal plane. The Magenta point is muon's effective position; red dots correspond to subinterval position of light production position (red circles represent position reconstruction uncertainty); the grin dot is the S3 position.

The time between S2 and S3 events in experiments [8] was below ~140 μs, and the clouds of unextracted electrons in the RED1 detector were fast-moving - in strong contrast to observations in the LUX detector.
The XeNu detector LLNL is smaller than the RED1 detector (see Fig. 4 for the XeNu design, also [14]). We observed e-burst in the XeNu detector with delays after previous S2 events up to 10-20 ms, so it is not only the large size of the LUX detector which leads to the slowing escape of unextracted electrons from the active surface (under anode).

3. Factors preventing surface electrons and ions removal

In the LUX detector, all grid holders and field shaping rings are embedded into PTFE dielectric structure. Only two small openings are present in PTFE walls where surface electrons and negative ions can leave the active area and reach grounded electrodes moving along the liquid surface [15].
The XeNu detector has no PTFE "wall around the liquid surface" (see Fig. 4), but in the design of XeNu (and, to our knowledge, of LUX detector), the rise of dielectric liquid level in a strong electric field (in a flat capacitor formed by the extraction grid and anode) was not considered. For the extraction voltage of 10 kV applied over about 10 mm gap in between the anode and extraction grid (gate), the liquid Xe level rise is about 0.1 mm. Bolozdynya's book on emission detectors [16] mentions this effect of the liquid level rise. In the XeNu detector's design, we were focused on reaching the highest possible extraction electric field and missed that step on

the liquid surface could produce a potential barrier for the surface electron or negative ions to leave the area under the anode. For electrons, moving 0.1 mm step down against the electric field of the order 1kV/mm could be a potential barrier of more than 10 eV (the exact value depends on the distance to the grounded electrodes and other geometry). This potential barrier is larger than temperature, which should lead to unextracted electrons and ions accumulation under the anode.
The anode grid sagging under the electric field's action can also produce a tangential component of the electric field, pushing surface electrons toward the center of the detector. This effect increases with the grid diameter (for fixed wires tension).
The RED1 and ZEPLIN III detectors have no anode grid but a solid aluminum electrode/mirror (see Fig. 2), so anode sagging was effectively absent.

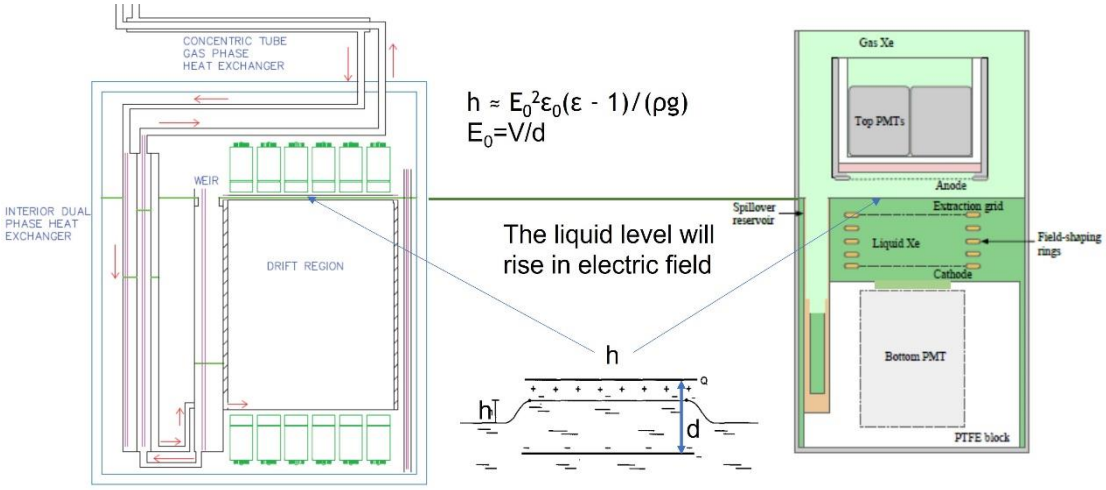


Figure 4. Left- part of LUX circulation loop (from [15]) Shown liquid level in the detector, in grounded copper weir reservoir and in dual-phase heat exchangers. Field-shaping ring and grid holders are embedded in PTFE walls (shown as grey hatching), but small openings are left at the liquid level position for liquid to "overflow" into the weir reservoir (to stabilize level position during circulation) and on the opposite side in front of the capacitance level meter (several level meters chowed in magenta).
Right- schematic of XeNu detector; there are no PTFE parts around electrodes and grids; liquid level position is stabilized with dielectric weir reservoir, the walls of Xe weasel are stainless still.
In both detectors there is a small increase of liquid level in a strong electric field applied between extraction grid and anode (dielectric liquid level rise in a capacitor).

The buckling of the extraction grid toward the flat anode in the RED1 and ZEPLIN III detectors produces a tangential field component moving surface electrons out of the center. The RED 100 detector has an anode grid (see [12]), so the surface electrons and ions accumulation due to anode grid sagging can be present (an electrostatic force acting on the anode grid in gas is larger than the force acting on the extraction grid in dielectric liquid).

4. Ordered states of surface electrons: Wigner crystallization and dimple lattice

Question arises if some kind of phase transition can take place on the liquid Xe (or Ar) surface as more electrons and ions accumulate. Several phase transition and instabilities are known for electrons and ions on the liquid helium surface, and on other dielectric surfaces and interphases, so we need to discuss them, though keeping in mind that some features can be different because of differences in interactions of free electrons and ions with different media.

Eugene Wigner predicted the electron ordering phenomenon in 1934. It was observed with electrons localized above the surface of liquid helium at low temperatures in the 1970-s (see for example [17]). It was extensively studied for ^{4}He and ^{3}He, solid hydrogen, helium and hydrogen films on dielectric substrates, and later for 2-D electron layers in semiconductors heterostructures (in cold 2D electron gas in semiconductors effects like quantum hall effects are present); see the review paper [18].

The appearance of electron ordering strongly affects transport properties. The electric conductivity of the electron layer sitting above helium film on a silicon wafer can drop several orders of magnitude during the Wigner crystallization transition [18]. The "rigid" triangular electron lattice pins to the substrate's local defects and electric field inhomogeneities.

Wigner crystallization requires the repulsion energy of electrons to be larger than the temperature and larger than the energy of the electron's zero-point motion (for a given distance between electrons) [18]. An electric field is required to accumulate a sufficient surface concentration of electrons (of the order of $(3 – 9)\ x10^8$ cm^{-2} in the temperature range 0.4 – 0.65 K– at temperatures for example [17]). At higher temperatures, another instability can be observed.

Because of the repulsion of electron and helium atoms at short distances, each electron pressed toward the liquid helium surface by an external electric field forms a microscopic dimple. If we increase the electric field, at some critical electric field it became favorable for electrons to form macroscopic dimples with many electrons in each dimple. Surface tension produces repulsion between dimples in addition to Coulon repulsion, and multi-electron dimples from a macroscopic triangular lattice on the liquid helium surface [19,20]. This lattice can have structural defects like dislocations [20] and can be pinned to inhomogeneities of electric potential and boundaries of the system. The exact size of dimples and the number of electrons in each dimple will depend on the history of charging and field application; typically dimples contained about $5\ x10^6$ electrons and have depth of a few tents of millimeter [20]. Fig.5 shows the results when the surface was initially charged and then the electric field was increased above the critical field for the transition.

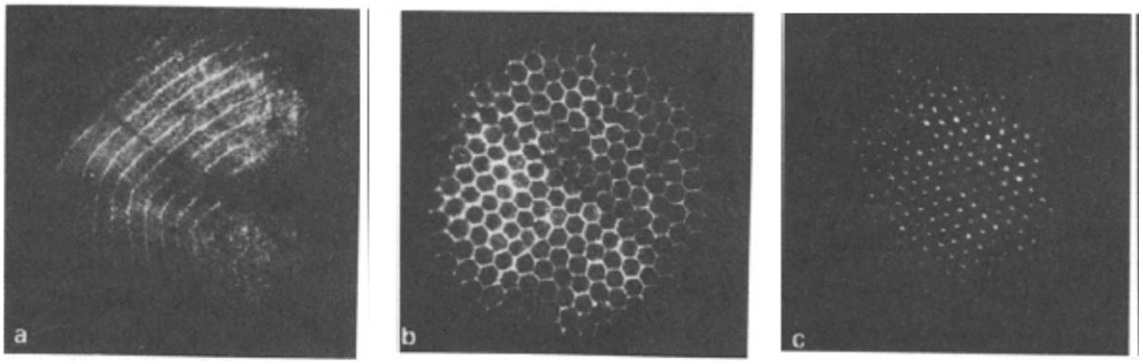


Figure 5. Formation of the dimple lattice on a He4 surface (T=3.5K) charged with electrons from above ([19]). Schlieren images (shadowgraph) of the surface deformation approximately 2s (a) and 6s ((b)and (c)) after the field had been increased above critical value E_c. The image plane was chosen that convex deformation of the surface (local maxima) appears bright in (a) and (b); in (c) bright correspond to local minima (dimple's bottoms). The distance between adjacent rows of dimples is close to 0.24 cm.

Transition in this scenario usually takes place in two steps. First, instability with characteristic wavelength $\lambda_c = 2\pi a$ appears. Then wave-like pattern transforms into a dimple lattice [19,20]. Parameters a and λ_c characterize the transition from the capillary to gravity dispersion law for

surface waves, a is called capillary length; $a = \left(\frac{\rho g}{\sigma}\right)^{1/2}$, where ρ is the density of the liquid, σ is liquid surface tension, and g is the gravity acceleration; a is of the order of millimeters, typical dimple size is about a, see [19,20] for more details.

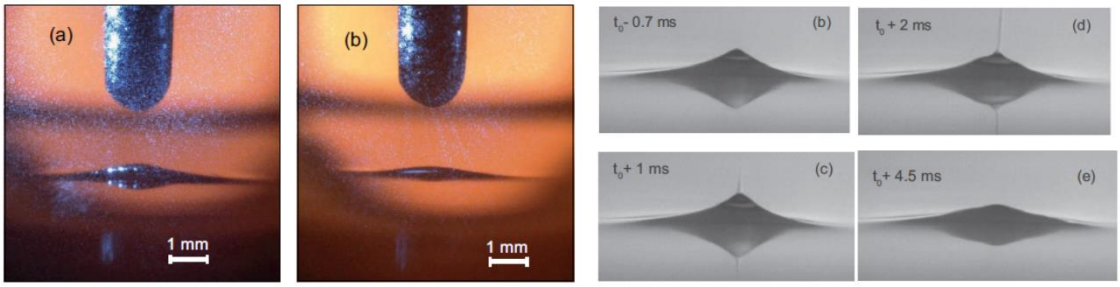
One also can keep charging liquid surface with electrons from above while keeping the applied electric field above the critical value. In this case, stable dimples will appear one by one and eventually form a triangular lattice (see [19]).

One can also charge the surface with positive ions coming from below and get a triangular lattice of hillocks, each hillock containing multiple ions. Moreover, authors of [19] describe that for some minutes time durations they were able to stabilize patterns where both positive hillocks and negative dimples were present.

We can summarize that formation of dimple lattice (oh hillock lattice) is behaving as a phase transition, and can demonstrate some hysteresis [20].

5. Geyser emission and electrospraying

With further increase of the electric field, the dimple lattice and hillock lattices on the liquid helium surface also became unstable. The multi-electron dimple on the helium surface can form a bubble with many electrons that "dive" into liquid. Hillocks formed by positive or negative ions can produce charged droplets or jets leaving the liquid. For helium, the effect of droplet formation was named geyser emission and was first observed with flat electrodes parallel to the liquid surface [21]. Recently, this instability was studied in more detail in an inhomogeneous electric field between a 1 mm radius semi-spherical electrode and a flat electrode [22]. This allows producing (stabilizing) of one hillock with the size scale of capillary length. Surface deformation and charged droplets/jets formation were filmed for positive and negative ions and for different (tip below or above the liquid surface) electrode orientations (see fig. 6)



Fgure 6. Left color photos- A static deformation of the free surface of superfluid He (Taylor cone) due to the trapped charge in a static electric field; (a) negative charge trapped; (b) positive charge. *T* = 2.1 K.

Right black and white frames of a fast video recording capturing the process of the charge escape from the Taylor cone. *U*pin = −390 V, *U*plate ≈ +900 V (ramp from +800 to +1800 V), *T* = 2.1 K, single-frame exposure time ≈0.19 ms; time *t* = *t*0 corresponds to the beginning of the jet emission.

In these experiments, the liquid surface was charged from below with ions and microscopic metal particles produced by laser ablation of a target in the liquid, and the electric field was increased in a step to make the hillock unstable.

No essential difference in electro-spraying was reported for the positively and negatively charged surfaces in these experiments. On the other hand, if one will look for the emission from liquid helium of electrons (each electron forms a microscopic bubble in liquid helium) and positive helium ions, there is no onset for electron emission, while a field above about 1.7

keV/cm required to see for emission (extraction) of positive ions []. So, electrons were not present on the surface of liquid helium in the case of the charging from below.

6. Interpretation of observations in Xe detectors and more questions

Wigner Crystallization likely can be observed for electrons localized around solid Ar or Xe surface at low temperatures. The other instabilities – like the formation of corrugations on charged liquid surfaces in an electric field and electrospraying at higher fields are much more common. The observations in helium (especially normal liquid) may be closer to other noble liquids, though the above discussion cannot provide the complete account or chart boundaries of transitions and instabilities we have in detectors. Likely, there are two critical surface charges concentrations: one is when the addition of more charges will lead to a hillock formation, and the other is when hillock starts to rise uncontrollably leading to droplet ejection. There also could be changes in single electron emission from the surface and in ionization signals extraction.

We summarize the author's interpretation of observations in the RED1 detector: as free electrons produced by muon in liquid Xe reach the liquid surface, part of these electrons escape to the gas and produce an S2 electroluminescence signal; a cloud of unextracted electrons move (linearly in time) toward the detector perimeter where it can produce S3 luminescence signal (if liquid level is off and anode support ring is not touching the liquid surface). The drift time is not exceeding ~140-160 μs. On its way, this cloud emits a small number of electrons into gas. There is a preferential direction for the unextracted electrons to drift, presumably because of the small tilt of the detector. We can add that likely here a cloud of free electrons can move with a surface wave along the surface (high mobility allows the free electron to stay on the wave crest).

Likely, in the LUX detector, unextracted electrons from ionization events are initially free surface electrons, but in case one sees an e-burst– these electrons do not drift anywhere from the S2 position. Possibly, charged hillocks are already present on the liquid surface, or many negative charges are present on the surface, so free electrons cannot drift and start to form a new hillock. With enough charges in the hillock, it bursts and injects charged droplets, ions, and electrons into gas. Some droplets can evaporate; negative ions in gas can lose electrons in collisions with neutral atoms.

In the LUX detector, the e-burst was absent on the part of the liquid surface adjacent to the opening in the PTFT wall leading to the copper weir reservoir [4]. At this location, both electrical force and surface flow are helping surface charges to escape, and E-burst instabilities are not happening. As e-burst are absent after large events here, some mechanism provides sufficiently fast transport of electrons out of the "hot spot" at the S2 position, so an "unstable" hillock is not forming. Hopping from hillock to hillock is not possible for helium, but we cannot exclude it on the liquid xenon surface.

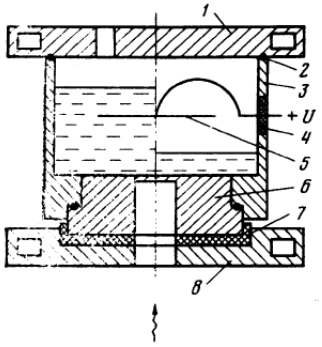
In this picture, we do not know what single-electron emission events are. This can be free electrons or ions escaping from "stable hillock," or negative ions coming to the surface with a large delay after free electrons and having some way to escape.

We also do not know how the surface concentration (density) of electrons and ions is varying in time: when it drops to the value prior to the ionization event, what this "equilibrium" value is, and what are mechanisms of the motion of the charges along the surface are.

7. Effects of surface charges on electron extraction and spectrum of events

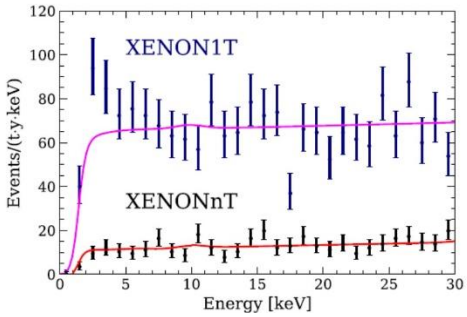
The electric field of surface charges makes the extraction electric field smaller in the liquid and larger in the gas. The other effect is the inelastic scattering of free electrons on the charged

layer. If an “field-overheated electron” loses kinetic energy near the surface, it will be trapped on the interface.
In fact, effects of strong suppression of electron extraction by surface charges were observed in the very first measurement of electron extraction efficiency or Ar, Kr and Xe in [7]. In the experimental cell used in these experiments (see Fig. 7), the side walls are at the same potential as the cathode, and for charges trapped at the liquid-gas interphase, it will be challenging to reach a positive electrode (the anode) by moving along Xe film on the walls. The paper [7] mentioned the effect of complete suppression of electron emission by liquid surface charging, especially for low voltages applied to the anode. It was possible to restore emissions by reversing the electric field direction for a short time. Unfortunately, we cannot conclude what effect was dominant there; moreover, extraction efficiency in this and any other experiment will be position-dependent if charged hillocks are present on the surface.



Fgure 7. Cell for electron extraction efficiency measurement from condensed noble gases (taken from rom [7]): 1- cover, 2-indium or Teflon gasket, 3- housing, 4- high voltage lead, 5- anode, 6- aluminum cathode liner (radiation from pulse X-ray tube was penetrating into liquid Xe through thin window in this liner), 7- insulating Teflon insert, 8- bottom

The most recent example (or question) is presented by the XENONnT experiment. In this detector, the active surface area (under the anode) is surrounded by a PTFE wall with no openings where surface charges can leave to the cryostat walls by drifting along liquid surface [21]; in addition the effects of grids sagging and the liquid level rise in the applied extraction field should be present in this detector leading to electrons and ions accumulation under the anode.



Fgure 8. Spectra of events in XENON1T and XENONnT detectors presented by Professor Shingo Kamaza at LIDINE 2023 conference (Warsaw, September 21-23, 2022).

The range of extraction fields in this experiment appears to be limited by a strong rise in a single-electron emission from certain locations on the liquid surface [21], so lower than-

designed voltage was applied, and low extraction efficiency also contributes to unextracted charge accumulation. Comparison of spectra of events in XENON1T and XENONnT experiments presented at the LIDINE 2022 conference reveals an interesting difference: in the XENONnT experiment the number of low-energy events decreases with energy, while in XENON1T the number of events is increasing with decreasing energy at the low-energy part of the spectrum (see fig.8). We can ask the question here if this difference in the shape of the spectrum can be the consequence of electron extraction suppression by the surface charges. It would be interesting to see the results of "S2 only analysis" for a few ionization electron signals where S1 light is too weak to detect and compare the shape of the spectrum to other Xe dark matter detectors. We can ask the same question about LUX results: S2-only analysis was not yet published; paper [4] points to the presence of single electron events and mention that number of few-electron events was insignificant (events were excluded by selection rules imposed in [4]).

E-bursts and multi-vertex events

General expectations are that for significant ionization events the electron extraction can exhibit non-linear effects. Electrons moving through the liquid surface in a strong extraction electric field should produce local overheating of the surface at the extraction spot. Also, an electron cloud dragging through the liquid by extraction field transfers momenta to the column of liquid, so waves of a jet can be produced on the liquid surface.

We made a striking observation for e-bursts in the XeNu detector: e-bursts were absent after significant single-vertex interactions with particles. The single-vertex event has a symmetric, about one μs long S2 pulse. For multi-vertex events or muon tracks, the S2 signal is longer, not symmetric, and can have more than one maximum. E-bursts were observed for multi-vertex events with smaller integral S2 intensity of than for single-vertex events where e-bursts were absent. Also, after-luminescence and delayed single-electron emissions were noticeably shorter for single-vertex events. Both local surface heating and jet/wave production can contribute to the observed phenomenon.

As dark matter searches start to consider scenarios where interactions will not be single-vertex-like in the Migdal effect- interactions of surface electrons, surface waves, and shock waves produced in bulk liquid by the primary particle interaction require more attention.

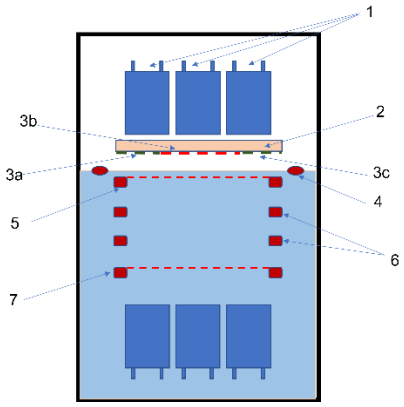
Discussion and conclusions

The presence of surface electrons, Wigner crystallization or formation of dimple/hillock lattice can be detected using small capacitors to excite and detect waves on the charged liquid surfaces [14]; coupling to surface waves is stronger in the presence of surface charges, and Wigner crystallization or other surface ordering charges the spectrum (wave propagation velocity)[]. Observation of hillock crystal should be possible with optical techniques, like in liquid helium experiments [15].

The problem with the potential barrier at the detector perimeter due to the small rise of a liquid level likely can be resolved by producing a tangential electric field component to remove electrons at the perimeter of the detector. An additional electrode can be placed on the liquid surface around the anode to make controllable changes to the tangential field component near the edges, see Fig. 9. Comparison of events spectra produced by Ar 39 measured for different potentials applied to the ring electrode can determine if extraction efficiency suppression is present.

One can replace a wire grid anode with a rigid quartz window with an evaporated metal grid or transparent electrodes to avoid anode grid sagging**.** Larger extraction fields will be beneficial; an increase in the gas pressure above the liquid (i.e., increase of temperature) can help to

increase the extraction field by staying away from gas ionization by electrons around anode wires.



Fgure 9. Possible experimental set-up design to control surface charge accumulation and to check effects of surface charges on backgrounds, electron extraction efficiency, 1- PMTs, 2 – quartz window with evaporated anode electrodes (transparent electrodes are possible), 3 a, 3b, 3c – anode electrodes on quartz window; one segment (like 3a) can be used to excite wave on liquid surface, than arriving of wave to the surface segment under 3c will cause electric signal at 3c, 4- ring electrode on the liquid surface to control (enhance or suppress) surface charges extraction at the perimeter of the active region (under cathode); 6- field shaping electrodes (to produce drift field in liquid), 7 – cathode.

To conclude, statical and dynamical effects associated with free electrons and ions on the surface of noble liquid could be rather complex- as we can see in the example of helium. Uncontrollable accumulation of unextracted electrons on the liquid-gas interphase in dual-phase Xe and Ar detectors produces uncertainties in experimental data interpretation and makes difficult direct comparisons of real and parasitic (excess) events spectra in different detectors. It is possible to develop tools for monitoring surface electron density; suppression of electron accumulation by changes in the detector design is also feasible. This should minimize uncertainties and allow more reproducible experimentation and comparison of mechanisms responsible for the excess backgrounds. Such studies will minimize risks associated with the high cost of uncertainties in planned multi-ton liquid Xe and Ar dual-phase detectors.
Using ideas and experimental techniques accumulated by helium physics for work on noble liquid detectors can help to accelerate searches for physics beyond the standard model.

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