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On Electromagnetic Units

by **H. B. G. Casimir**

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Once upon a time there was in a far away country a great, great kitchen in which many cooks plied their trade and in which there was a great profusion of pots and pans and kettles and cauldrons and bowls and basins of every size and kind and description. Some of these vessels were empty but others contained eggs or rice or apples or spices and many other delectable things. Now the cooks, if they were not busy broiling and baking and cooking and frying and preparing sundry soups and sauces, amused themselves with philosophical speculation and so it came to happen that the art of tagenometry (from *ταγηνον*, a frying-pan) was developed to great perfection. Sometimes it was even referred to as panmetry, the art of measuring everything, but the ignorant scullions, misinterpreting the word, promptly also spoke about potmetry, much in the same way in which the transatlantic chefs have supplemented the hamburger with a cheeseburger.

To every vessel tagenometry assigned a volume V. This was measured in cubic inches and determined by measuring dimensions with great precision and by then applying the formulae of solid geometry or in case of irregular shapes by numerical integration on a beanbeaded abacus. But to every vessel there was also assigned an entirely different quantity, the volumetric displacement W. This was measured in gallons and determined by filling the vessel with water, pouring out the water, weighing said water in pounds avoirdupois, correcting for temperature and dividing by 10. The ratio of volumetric displacement and volume was referred to as the volumetric constant, $\varepsilon = W/V$. In the course of time it became clear that this volumetric constant had the same value for every empty vessel; this became known as the volumetric constant of empty space or ε_0. But for other vessels the volumetric constant behaved often in an erratic way. It changed after thermal treatment, or simply with time, it depended on the speed of measurement. Also the dynamic behaviour of moving non-empty pans posed curious problems.

One day a wise man entered the kitchen and after having listened to the worried cooks he said: 'I can solve your problems. There is really only one tagenometric quantity, let us call it the volume and measure it in cubic centimeters. Weighing water will give the same value for an empty vessel if you take the weight in grams. So your volumetric constant of empty space is just unity. But in a non-empty pan part of the volume is occupied by edibles like potatoes or pears or plums; let us call this volume P. Then, with the water-method you determine $V - P$. In many cases P will be proportional to V, that is $P = \varkappa V$. Then the water-weight volume, your volumetric displacement is $W = V - \varkappa V = (1 - \varkappa) V$ and hence $\varepsilon = 1 - \varkappa$. What you really should study is P and its dependance on the constitution and preparation of the victuals. And instead of studying the dynamics of a non-empty pan, you should study the motion of the things it contains,' The cooks understood, yet they looked crestfallen. 'But our beautiful units' they said. 'What about our goldplated pounds and ounces and drams? Look at that wonderful half-perch in yon corner, neatly subdivided in 99 inches. It would be ill-convenient to change all that.' The wise man smiled. 'There is no real need to change' he said. 'As long as you are sure to remember that ε_0 is just a way to change from one unit to another and that P and $\varkappa$ are the only physically relevant quantities, you can work in any system of units you like.'

The years went by. The wise man had died, new generations of cooks worked in the kitchen and got restive over the principles of tagenometry. 'How crazy', they said. 'Isn't it obvious that V and W are quite different quantities, since they are determined in quite different ways? And why should the volumetric constant of empty space be unity? Is a pot of rice not just as good or better than an empty pot?' These protests prevailed. It was decided at an international congress that even if volume and volumetric displacement were identical in magnitude the one should be measured in Euclid – this being a cubic centimetre – the other in Archimedes. The volumetric displacement of empty space – although equal to unity – had the dimension Archimedes/Euclid. And after having created order in this way, the new generation has returned to inches and pounds, and brands as reactionary anyone who heeds the wise lessons of the wise man.

That is how to-days cooks spend their moments of leisure; let us hope that their cuisine will not suffer.

Vacancy Diffusion in Germanium

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Abstract. The theory of precipitation from supersaturated solutions in elemental semiconductors for impurities with comparable substitutional and interstitial solubility is discussed. It is shown that the precipitation time constant is related to the vacancy diffusion coefficient. This relation can be used to estimate the migration energy of monovacancies. As an illustration Tweet's data on copper precipitation in germanium are analysed, giving ~ 0.2 eV for the monovacancy migration energy.

1. Introduction

The properties of simple point defects in silicon and germanium have recently received considerable interest, in part due to the practical importance of radiation effects in these semiconductors [1–5]. The detailed studies of monovacancies in *silicon* by means of electron spin resonance have led to surprisingly low energies of migration, namely

$$E_{1V}^{M} = (0.33 \pm 0.03)\ \text{eV in } p\text{-type Si (neutral)},$$
$$= (0.18 \pm 0.02)\ \text{eV in } n\text{-type Si (double negatively charged) [6].}$$