Dissolved oxygen sensing by positronium for hypoxia PET

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Positronium (Ps) is formed in the human body during a positron emission tomography (PET) scan, and the lifetime of ortho-Ps (o-Ps), i.e., time to decay into photons, depends on the environment [1,2], especially oxygen partial pressure (pO_2) due to the unpaired electrons in O_2; The higher pO_2, the shorter the Ps lifetime. Knowing the distribution of pO_2 is important for cancer patients because hypoxic cells are often resistant to radiation therapy and chemotherapy[3]. We estimated the pO_2 resolution by comparing Ps lifetime in three samples: N_2-saturated water (pO_2=0 mmHg), air-saturated water (pO_2=159 mmHg), and O_2-saturated water (pO_2=750 mmHg); each included 5-μCi ^{22}NaCl.

We found a linear relation between pO_2 and o-Ps decay rate ($\Gamma/\mu s^{-1}$), which is the inverse of the lifetime. The linearity is because the probability of o-Ps encountering O_2 is proportional to pO_2. The solid line in Fig. 1 is given by Eq. (1) and provides a way to convert the measured Ps lifetime into pO_2.

$$pO_2/\text{mmHg} = 26.3(1.1)\times\left[\Gamma - 519.9(1.6)\right] \quad (1)$$

We estimated the pO_2 resolution by considering the uncertainty of the line in Fig. 1 and Poisson noise; it was about 17 mmHg for 100 million counts from the region-of-interest (5 mmHg for 1 billion counts) as shown in Fig. 2. The resolution is sufficient to distinguish the hypoxic cells (pO_2=6 mmHg [4]) from healthy cells (pO_2=41 mmHg [5]) in a human liver.

Conventional PET is based on the accumulation of radioactivity. The new method is based on the lifetime of o-Ps. These two methods can be implemented simultaneously. The new method increases the amount of information obtained by PET and may improve the outcome of cancer treatments.

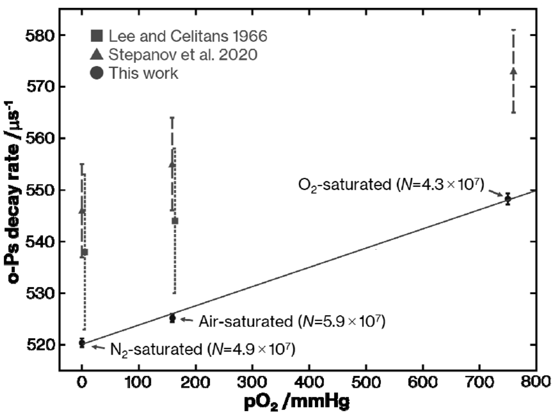

Fig.1. Relation between pO_2 and o-Ps decay rate: squares (Lee [6]), triangles (Stepanov [7]), and circles (this work).

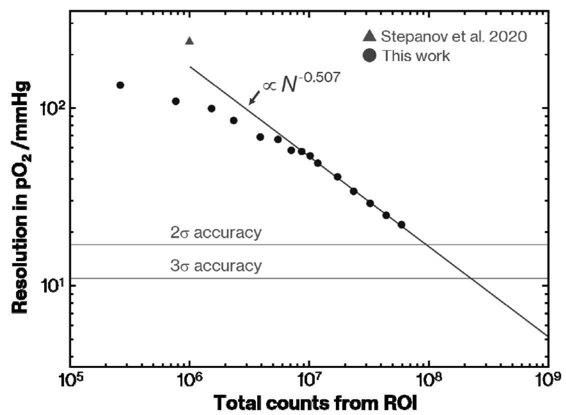

Fig.2. Relation between pO_2 resolution and number of counts: triangle (Stepanov [7]), and circles (this work).

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