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Volumetric properties of dilute (D-glucose + H_2O) solutions at temperatures from (293.15 to 433.15) K and pressures from (0.10 to 50.00) MPa

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ABSTRACT

The densities of aqueous solutions of D-glucose were measured at temperatures from (293.15 to 433.15) K and pressures from (0.10 to 50.00) MPa using a vibrating-tube densimeter. Apparent molar volumes $V_{\varphi,m}$ and partial molar volumes at infinite dilution V^{∞} were calculated from the experimental results. V^{∞} increases as temperature increases and varies linearly with temperature above ~300 K. In addition, V^{∞} does not vary as a function of pressure up to 50.0 MPa. Comparison of these results with previous studies indicate excellent agreement and significantly extend the experimental database for aqueous solutions of D-glucose to elevated temperatures and pressures.

1. Introduction

The search for life in our solar system is based on understanding analogous environments on our own planet that may have hosted the emergence of life. Thus, the question of the origin of life (based on what we know from Earth) can be approached as a geochemical question to determine environmental habitability (i.e., what environments meet the minimum requirements for life): an aqueous (liquid water) environment, available molecular building blocks for life, and a source of environmental energy. Submarine hydrothermal environments meet these geochemical requirements and may have hosted the emergence of life on Earth. Relatively little is known about the nature of early life on Earth, from the first metabolic pathways to the temperatures of its emergence. Recently, organisms such as the hyperthermophilic archaeon, *Methanopyrus kandleri* (strain 116), isolated from deep sea hydrothermal vents, have recently been found to grow in laboratory environments with temperatures up to 122 °C [1]. Terrestrial extremophiles have caused us to reconsider the broader environmental conditions that may host life. Analogous habitable environments may exist on other solar system bodies such as Mars and Europa.

The need to accurately model and understand reactions among organic compounds and biomolecules in aqueous solutions has led to a number of experimental studies to determine the thermodynamic properties of these compounds. Unfortunately, there is a paucity of data for important compounds at elevated temperatures and pressures. Experimentally determined volumetric properties of aqueous solutions at non-standard conditions will provide direct tests of current estimation methods and aid in the refinement of these methods. The ultimate goal of this research is to develop a thermodynamic database of aqueous organic mixtures at high temperature and pressure in order to understand the metabolic processes of thermophilic organisms and aid development of a more accurate geochemical model for the origin of life in aqueous environments.

D-glucose is a monosaccharide important in biology as an energy source, metabolic intermediary, and important step in cellular respiration. It is essential to most primary metabolic pathways by serving as the main source of energy in the Krebs and the reverse citric acid cycles. Through the Embden-Meyerhof pathway, it is oxidized to pyruvic acid thus initiating a metabolic cycle that ultimately yields ATP, the energy currency of all living organisms.

2. Experimental

Density measurements were obtained with a commercially available Anton Paar vibrating-tube densimeter (DMA HP). The

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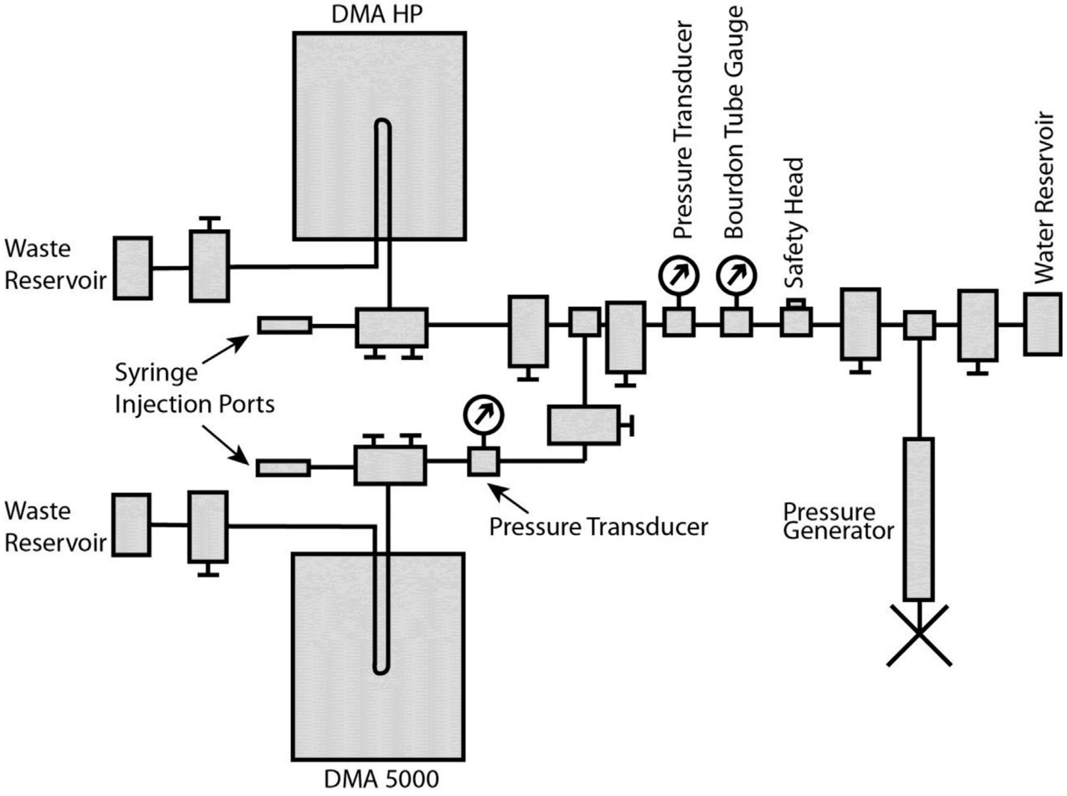

Fig. 1. Schematic diagram of the fluid manifold for the DMA 5000 and DMA HP densimeters.

DMA HP is an external measuring cell controlled by a DMA 5000 densimeter. Fig. 1 presents a schematic of the manifold for injection of fluids into the densimeters. The fluid manifold was constructed from standard high-pressure fittings, valves, 1/8 in. (3.175 mm) diameter tubing (taper seal) and other components with a 15,000 psi (103.40 MPa) working pressure constructed of 316 stainless steel tubing obtained from High Pressure Equipment. Fluids were injected into the vibrating tube with gas-tight syringes at 0.10 MPa. The manifold and instruments were pressurized using a piston screw pump (High Pressure Equipment) with purified H_2O as the pressure medium. The fluid pressure was monitored with Stellar Technology pressure transducers with a maximum uncertainty of ±0.007 MPa. Temperature was measured with an integrated platinum thermometer with an accuracy (as determined by the manufacturer) of ±0.05 K.

The DMA HP is capable of measurements at $0.10 \leq (p/\text{MPa}) \leq 70.00$ and $\leq 473.15(T/\text{K})$. The fundamental equation for calculating densities of fluids by vibrating-tube densimetry is

$$\rho - \rho_o = \mathrm{K}(\tau^2 - \tau_o^2) \tag{1}$$

Table 1
Specifications of chemical samples used in this study.

Chemical Name	Source	Purity (supplier)	Purification Method
Water	Fisher Optima,	≤10 ppb ionic impurities	degassed by boiling and vacuum
NaCl	Fisher	≥99.5%	none
Methanol	Fisher Optima	≥99.9%	none
D-glucose	Sigma	≥99.5%	none

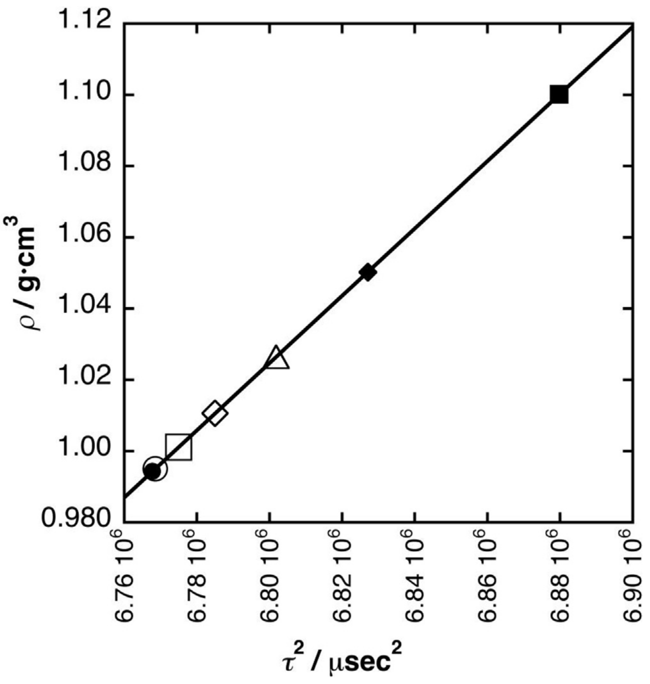

Fig. 2. Square of the period of vibration τ^2 against density ρ at $T = 413.5$ K and $p = 5.00$ MPa for three reference fluids: ●, pure water; ◆, $m = 1.5000$ mol·kg^{-1} NaCl solution; ■, $m = 2.9986$ mol·kg^{-1} NaCl solution; and four aqueous glucose solution analytes: ○, $m = 0.0089$ mol·kg^{-1}; □, $m = 0.0993$ mol·kg^{-1}; ◇, $m = 0.2494$ mol·kg^{-1}; △, $m = 0.5027$ mol·kg^{-1}. The line represents a linear least-squares fit to the results for the reference fluids. The densities of the analytes are determined by referencing the measured period of vibration to the regression line.