A NOVEL IDEA ABOUT THE NATURE OF PHASE Q. D. Heymann, Department of Geology and Geophysics, Rice University, Houston TX 77005, USA, and R. D. Vis, Department of Physics and Astronomy, Free University of Amsterdam, 1081 HV Amsterdam, The Netherlands.

Phase Q was defined as the substance (or substances) in HCl-HF resistant residues of the Allende meteorite which dissolved in HNO₃ and which is the carrier of the so-called "planetary noble gases" [1]. Several hypotheses about its nature have been advanced, but its true nature is still unknown. Here we propose that Q is some type of carbon nanotube.

The following is firmly known about Q. The substance does not dissolve in, nor is it chemically destroyed by HCl-HF [1]. Q releases the planetary noble gases when treated with HNO₃ and other oxidizing chemicals [1,2]. Q releases the planetary noble gases when heated in vacuo to temperatures in the range 1200 to 1600 °C [3]. Among the unknown and poorly known characteristics are the following. Although some fraction of the HCl-HF resistant residues dissolves in HNO₃, it has not been unequivocally demonstrated that what dissolves is actually Q. In several studies, the chemical action of HNO₃ on Q was named "etching", and it was proposed that the noble gas atoms are sited on, or near surfaces of Q [4]. The nature of Q was long an issue of lively debate. It was suggested that Q was apparently an Fe,Cr-rich sulfide with lesser amounts of Ni, Al, and Mg [1,5]. Other investigators concluded that Q was a carbonaceous phase, but did not specify its structure [6-8].

We propose that Q is a carbonaceous phase whose structure belongs to the family of carbon nanotubes. We definitely eliminate the carbon structures of fullerenes and of carbon onions from consideration. Fullerenes were proposed as carriers of trapped noble gases gases in meteorites [9] and 100 ppb of fullerenes were found in a small sample of the Allende meteorite [10]. However, whereas all studied bulk samples and HCl-HF resistant residues of Allende contained trapped planetary gases, hence Q, up to 300 g of this meteorite were shown to be free of fullerenes [11]. Carbon onions may occur in the Allende meteorite [12], but they appear to be resistant to HNO₃ [13].

Carbon nanotubes were discovered by Iijima [14] among the solid products of arc-discharge evaporation followed by condensation of carbon in an inert atmosphere. These tubes consisted of from 2 to about 50 coaxial graphitic cylinders with diameters ranging from a few to a few tens of nanometers. Their lengths were typically on the order of micrometers. Most of the tubes were closed at both ends [15,16]. Today, this class of nanotubes is called "Multi-Wall Nano Tubes", or MWNT's. MWNT's have also been produced by laser-evaporation of carbon and condensation under homogeneous gas-phase conditions [16]. The end-caps of MWNT's were removed by laser evaporation and by the burning of tips heated in the range 1000 to 1500 °C in several millitorr of oxygen [17]. The caps are probably also removed by HNO₃ [18].

Single-Wall Nano Tubes (SWNT's) are formed by the condensation of carbon in the presence of cobalt and nickel vapors as catalysts [19-21] and by metal-catalyzed disproportionation of carbon monoxide [22]. The ends of SWNT's are usually closed by fullerenic hemispheres of C₁₂₀ [23]. When formed by the methods cited, SWNT's self-organize into "ropes" of 100 to 500 SWNT's. Long SWNT's can be cut to shorter "pipes" by refluxing in nitric acid followed by sonication in an oxidizing mixture of nitric and sulfuric acid [24]. It is possible that the ends of SWNT's are opened by a milder HNO₃ treatment.

Noble gas atoms can be incorporated endohedrally into fullerenes [25-27]. Large amounts of molecular hydrogen have been stored in SWNT's [28]. Because of structural similarities of fullerenes and carbon nanotubes there are good reasons to think that nanotubes might be superb bottles for the planetary noble gases. The incorporation might have occurred, for instance, when nanotubes onto which noble gas atoms were absorbed exohedrally were exposed to a transient shock wave.

Elemental carbon was most extensively studied in the CV3 carbonaceous chondrite Allende. The earliest studies concluded that Allende carbon was very fine-grained and poorly crystallized [29-31]. Hayatsu et al. [32] concluded that the carbon in Allende was not graphite, but carbynes and Whittaker et al. [33] proposed that carbynes were the carriers of the primordial noble gases in chondritic meteorites, a hypothesis that was later proven to be incorrect. Several studies of the carbon were then performed using Transmission Electron Microscopy (TEM) and High Resolution TEM (HRTEM) techniques [34-39]. The morphologies of carbon were called "glassy" and "turbostratic", but some of these structures resemble carbon onions and nanotubes as was pointed out by Becker et al. [40].

A number of the recent microscopic studies of carbon nanotubes have revealed additional similarities between morphologies of carbon in the Allende meteorite and in laboratory-produced carbons containing carbon nanotubes. Pang et al. [41] reported sheets of graphite with thickened rolled rims and
crystalline carbon with a radial structure. Other examples include Ando and Iijima [42], Dravid et al. [43], and FitzGerald et al. [44].

**Summary:**

Our hypothesis rests on the following cornerstones:

1. Nanotube-like morphologies of carbon have been observed in the Allende meteorite. Also unusual carbon morphologies which have been seen to occur in laboratory-produced carbons containing nanotubes.

2. Nanotubes can probably store large amounts of noble gas atoms. Because of this, nanotubes need not be strikingly abundant constituents of carbonaceous matter in meteorites.

3. Nanotubes are probably "opened up" when treated with HNO₃ in which case they will release endogenically trapped gases.

4. Since the formation of SWNT's requires more specialized conditions than the formation of MWNT's, we think it to be more likely that Q is in the family of MWNT's.

**References:**