Gas pump with a magnetically coupled piston

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A simple pump has been constructed which is useful for stirring gas in a sample cell for gas-phase nonlinear optics experiments. It uses a piston and has been operated at gas pressures from 0 to 200 atm, and at temperatures from room temperature to 200 °C.

In recent gas-phase nonlinear optics experiments it has been necessary to prepare gas mixtures with very homogenous composition and temperature inside the measurement cell.[1] The gas cell contains a relatively massive electrode structure,[2] which is in poor thermal contact with the cell walls, and which leaves no room for an effective stirring device. To effectively mix the gas in the cell we have devised a reciprocating piston pump which is compatible with high-purity, high-temperature, and high-pressure gases, and which may be operated without disturbing the critical optical alignment of the gas cell. The periodic-phase-matched electric-field-induced second-harmonic generation (ESHG) method we employ for measuring molecular hyperpolarizabilities has been described previously.[3–5] To make these measurements one compares ESHG signals at phase match for sample and reference gases in rapid succession in the same cell. There are two problems that are solved by the pump. The first is temperature gradients. A vertical temperature gradient is established in the gas when the cell is filled and this causes a downward beam deflection. For example, a thermal-gradient-induced deflection of 0.1 mrad is measured after filling with 10 atm of N_2 gas, and this deflection may persist for as much as an hour but is erased immediately by stirring. A gradient of 0.02 °C/mm is sufficient to cause this deflection. This deflection causes signal variations as large as 10% when the optics following the gas cell are imperfectly aligned. Gross differences between the gas temperature and the cell wall temperature are also reduced by stirring, as is determined by using the phase-match pressure of the gas as a sensitive gas thermometer. The second problem solved by the pump is that of making homogeneous mixtures of sample vapor and buffer gas when studying less volatile molecules.[1] The progress of mixing is easily monitored by filling to a density slightly above phase match, on the steep shoulder of the phase-matching peak, and observing the ESHG signal at constant sample density. Changes in composition of 0.01% will be readily apparent in this way. In initial experiments without the pump the signal required several hours to stabilize, whereas with the pump a homogenous sample is obtained in several minutes. In recent unpublished ESHG experiments using the pump with pure gases, the long-term reproducibility of measurements has improved from the 1% level to the 0.1% level.

The layout and the essential construction details of the apparatus are shown in Fig. 1. The pump cylinder is internally divided into two compartments by a sliding piston. On the forward stroke of the piston, gas enters one end of the pump and is expelled from the other end. On the return stroke, the flow direction is reversed. The ends of the pump are connected to the corresponding ends of the gas cell by narrow tubes, as shown in Fig. 1(a). The swept volume of the pump cylinder is about half as large as the internal volume of the gas cell, so each forward and back stroke of the piston transfers the entire contents of the gas cell into the pump and then back again. Mixing is effective because the reciprocating flow tends to produce chaotic trajectories in the cell, and because the flow in the connecting tubes is turbulent. In the present apparatus, where the swept volume is about 350 cm^3 and the connecting tubes are 16 cm long with 8 mm i.d., the critical Reynold's number is exceeded for air at a pressure >1 atm when a single stroke of the piston takes 3 s or less. At higher gas density and piston velocity, the flow will become turbulent in the pump cylinder and gas cell as well.

The annular gap is 0.1 mm between the 4-cm-long$\times$4-cm-diam piston and the cylinder wall. One may employ such a wide clearance between the piston and the cylinder, without significant leakage of gas around the piston, because only a small pressure difference is required to move the gas. The weight of the piston is reduced by boring 3-cm holes into each end, leaving a 1-cm-thick central partition [see Fig. 1(b)]. The piston is made of soft iron and is moved inside the cylinder by means of an external magnet[6] with "Γ"-shaped iron pole pieces [see Fig. 1(c)]. The lon-

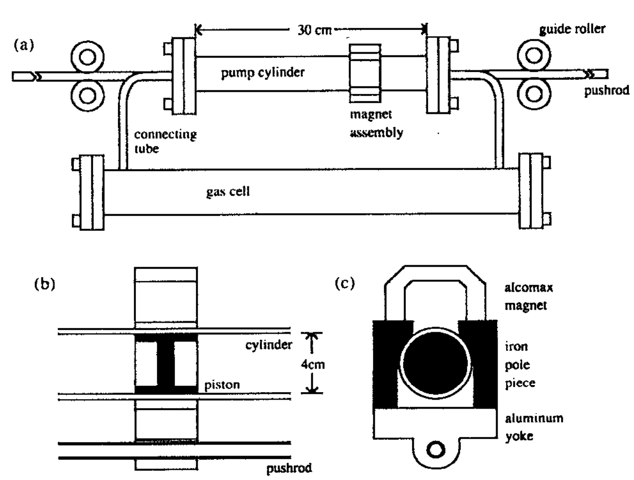

FIG. 1. The top view of the apparatus is shown in (a), followed by a longitudinal section (b) and a transverse section (c) through the center of the magnet assembly and piston. The surfaces of section of the soft iron parts of the magnetic circuit are shown shaded.

gitudinal magnetic restoring force coupling the piston to the magnet arises because the reluctance of the magnetic circuit is minimized when the piston is longitudinally centered in the magnet assembly. The Γ-shaped pole pieces also produce a vertical magnetic force which can levitate the piston. The pole pieces have been trimmed so that the levitating force balances the piston weight within 10%. It is important to reduce the contact force between the piston and cylinder to minimize friction and wear inside the pump. The vertical force on the piston was measured as the change in the apparent weight of the magnet assembly when the piston completes the magnetic circuit. The magnet assembly is supported on a 13-mm-diam stainless-steel tubular pushrod running between pairs of grooved ball bearing rollers. This pushrod mechanism translates the magnet assembly with low friction and without allowing the assembly to tip and jam against the outside of the cylinder.

The stainless-steel pump body is constructed by welding flanges onto a tube with a 4-mm-thick wall. Each end is attached with 12 bolts of 1 cm diameter, and sealed using copper gasket and knife edge seals. This construction allows the pump to be operated at pressures up to 200 atm at room temperature, and up to 200 °C at lower pressure or under vacuum. For vacuum bakeout or high-temperature measurements the entire pump and gas cell are placed inside an oven, with just the ends of the pushrod projecting outside.

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[6] U-shaped (2.25×1.75×1.38 in.) Alcomax magnet from Edmund Scientific Co.