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A0 and A1 Studies on the Violin Using CO_2, He, and Air/Helium Mixtures

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Summary
A determination of the A0 and A1 cavity modes (here called collectively ”air modes”) in the violin has been made using CO_2, helium and air/helium mixtures. The use of a “glove bag” enabled the atmosphere surrounding the violin to be better controlled than relying on the difference in density to displace the air inside the instrument. The cavity modes in CO_2 and He were moved to frequencies as predicted by theoretical considerations. A single resonance peak for A0 in CO_2 and air became a doublet in He and more complex in air/He mixtures. The A1 peak was not influenced as much as A0 and remained single under all conditions. These observations were interpreted as interactions between cavity resonances, with mode frequencies determined by the current gas mixture, and body resonances.

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1. Introduction

Bissinger and Hutchins [1] have explored the coupling between the two lower cavity modes in the violin (A0 and A1, “air modes”) and the body modes by replacing the enclosed air with carbon dioxide (CO_2). They extended their work with experiments using Freon 22 (CCl_2F_2) [2, 3]. Both gases being more dense than air lowered the frequencies of the air modes. The interest here lay in the change in frequency and height of the body resonances as the coupling with the internal gas changed.

An attempt has been made to further the work by Bissinger and Hutchins by using helium (He) as the substitute gas. The gas used was ”balloon mix” which contains a variable amount of nitrogen (N_2), nominally 5%, in the following referred as He(5N). This low nitrogen content was not expected to influence the results significantly compared to pure helium. The gases most readily available, and free from any hazard, that could be used in this kind of experiment are listed in Table I.

The velocity ratios $c_{\text{gas}}/c_{\text{air}}$ were calculated using the equation

$$\frac{c_{\text{gas}}}{c_{\text{air}}} = \sqrt{\frac{\rho_{0\text{air}}\gamma_{\text{gas}}}{\rho_{0\text{gas}}\gamma_{\text{air}}}}, \tag{1}$$

where ρ_0 is the density, and γ is the ratio of the specific heat of the gas at constant pressure C_p to that at constant volume C_v. For sounds of the same wavelength the frequencies in two gases are proportional to the velocities.

Typical frequencies in air of the violin cavity modes A0 and A1 for the violin used in the experiments, and the expected frequencies in different gas mixtures are included in Table I. From the velocity ratios it is readily seen that helium raises the frequencies of the cavity modes by a substantial amount, about a factor 3. This frequency shift would be enough to decouple them from body modes below 600 Hz, in particular the main body modes T1 and C3 which occur in the range 460 to 580 Hz.

Following some initial experiments in He(5N) which resulted in resonance peaks for A0 and A1 with shapes (doublets) very different from those previously published, it was decided to repeat the determination in CO_2 and mixtures of air and helium. The latter experiments would successively take the A0 mode into the region of body modes.

2. Experiments

2.1. Measurement setup

The experimental setup is shown in Figure 1 with a general view, and a second more detailed view where excitation and microphone transducers for detecting A0 and A1 are shown inserted into the f-holes. A microphone above the instrument and an impulse bar used for striking the bridge on the E string side and a magnet/coil detector for measuring the bridge motion on the G string side, are also visible.

Two kinds of measurement were made; (1) the response of the violin as a result of impulse excitation at the bridge and recording via an external microphone or magnet/coil to study the frequency and height of peaks linked with sound production and body peaks respectively, and (2) internal excitation and response measurements (called ”air-to-air” whether using air or a substitute gas CO_2, helium,

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Table I. Properties of gases suitable for studies of violin cavity modes. It was assumed that the He(5N) was moisture free. The columns f_{A0} and f_{A1} give typical values of the A0 and A1 frequencies in air for the violin in the experiments, and the expected frequencies in different atmospheres, all at room temperature. *: Handbook of Chemistry and Physics 42nd Ed. 1960/1, p. 2288. $^\#$: Handbook of Chemistry and Physics 46th Ed. 1965/6, E-29.

Gas	molar mass [g/mol]	density ρ_0 [kg/m^3]	γ *	velocity at 0 °C c $^\#$ [m/s] $^\#$	velocity ratio $c_{\mathrm{gas}}/c_{\mathrm{air}}$	f_{A0} Hz	f_{A1} Hz
He	4	0.178	1.66	965	2.928	820	1420
He(5N)	5.2	0.232	1.66		2.568	719	1245
Ne	20	0.900	1.64	435	1.296	363	628
N_2	28	1.251	1.404	334	1.017	285	493
Air	29	1.293	1.403	331	1	280	485
Ar	40	1.784	1.668	319	0.928	260	450
CO_2	44	1.977	1.304	259	0.780	218	378

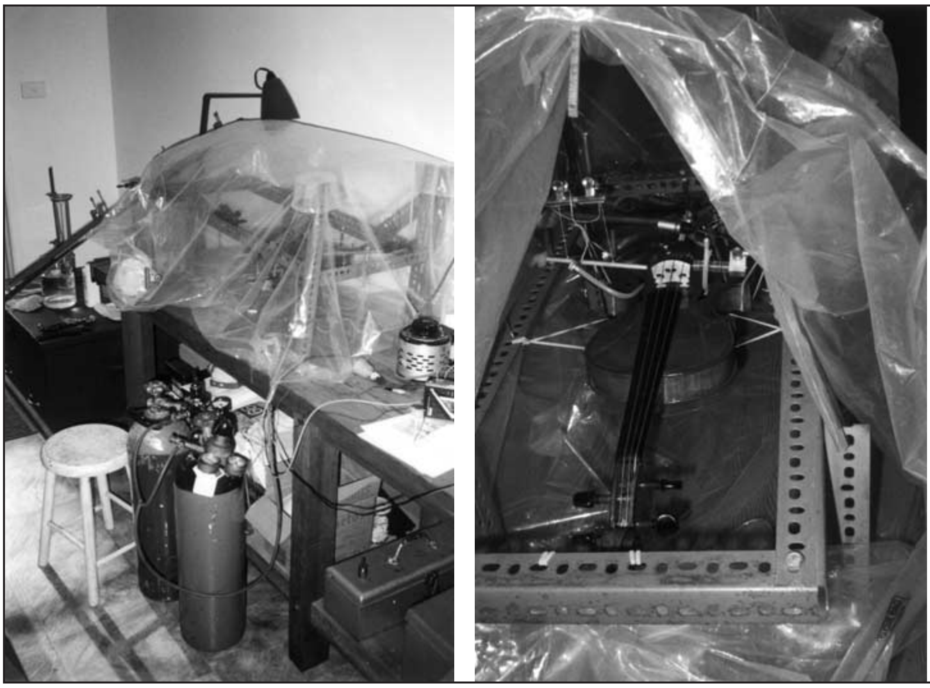

Figure 1. (a) General view of the experimental setup with the glove bag. The violin is turned upside-down for measurements in He(5N). (b) Typical setup inside the glove bag showing transducers mounted on the violin with acoustic exciter and microphone tubes passing into f-holes, impulse pendulum and magnet/coil at the bridge, and microphone above the violin.

or mixtures of air/He) to study cavity modes, A0 and A1. Only the study of cavity modes in (2) will be reported in the following.

The cavity modes A0 and A1 were driven with a small earpiece exciter and recorded with a small piezoelectric microphone. Each of these two items was inserted into one end of a separate polythene tube. Each tube was then passed through an f-hole to reach near the lower end block. A signal generator with an attached frequency counter and amplifier was used to scan the frequency range of interest. The level of excitation was 60 dB at the open end of the tube attached to the earpiece exciter. The same excitation level was used in all determinations of cavity resonances. The signal from the microphone was amplified and fed to a digital voltmeter. Voltage readings were taken at 20 Hz intervals.

In an initial stage of the experiments, the helium atmosphere was metered in from a cylinder via a tube inserted into the inverted violin through one of the lower ”eyes” of one f-hole. It was expected that the helium would displace the air and remain in the body cavity with a small continuous flow to minimize mixing with air in the f-holes. It subsequently transpired that for consistent results the experimental setup was best placed in a ”glove bag” (normally used in chemical experiments), which allowed the violin to be completely surrounded with helium.

2.2. The need for a ”glove bag”

With helium, initially without a ”glove bag,” the results were not stable, although there was an upward shift in the frequencies of the resonance peaks. The frequencies of the two cavity modes A0 and A1 were not constant and usually lower than expected. There were also additional peaks in the interval between A0 and A1 that were variable in frequency and width. These problems were eliminated by enclosing the setup in a ”glove bag” that could be sealed (see Figure 1).

The artificial atmosphere was supplied continuously into the bag during the experimental runs. Atmosphere was supplied through the f-holes as before, and an additional tube reached to the top of the bag, so that the violin was completely surrounded with helium or air/He mixtures. The system was considered stabilised when the A0 and A1 peaks stopped moving to higher frequencies. This procedure gave consistent and reproducible results. Once filled with helium, the large seal at the bottom was closed by folding the bag over a thin batten and clamping it against a second batten. After sealing the large opening, the inlet tube at the bottom of the bag (diameter about 1 cm), through which went the rubber gas tube to the violin and all leads for the transducers, formed a restricted outlet for excess atmosphere. This arrangement kept the bag inflated. The ”gloves” allowed manipulation of the impulse pendulum when required.

When CO_2 was the substitute gas, the violin was turned over to normal position and the glove bag was rearranged with the inlet to the bag at the bottom and the exhaust at the top for the gas to displace the air from below. The CO_2 was supplied from a cylinder at a rate that allowed the temperature of the atmosphere in the glove bag to stabilise at ambient.

3. Results

3.1. Measurements in air, CO_2 and He(5N)

The results for A0 and A1 determined in air, followed by a determination in CO_2 in the same session, are shown in Figure 2. The peaks in air were found at 270 Hz and 490 Hz. The ratio of the higher to the lower frequency was $f_{A1}/f_{A0} = 1.82$. A shift of 5 Hz in both frequencies would bring the ratio close to 1.73, the ratio obtained for this violin in earlier experiments. The discrepancy gives an indication of the variability in frequency determination between measuring sessions.

In CO_2 the peaks were moved down in frequency to about 215 Hz (0.80) for A0 and 385 Hz (0.79) for A1, the numbers in parentheses giving the downshift ratio. The observed frequencies were close to expectations according to the calculated velocity ratios in Table I (0.78).

The same two modes determined in air and He(5N), respectively, again in one session, are shown in Figure 3. In air, A0 now occurs at 275 Hz (+5 Hz) and A1 at 480 Hz (−10 Hz). The number in parenthesis give the differences in frequency compared to Figure 2. These shifts are due to a combination of measurement errors and changes in temperature and humidity, as the two measuring sessions took place a week apart. The peaks in He(5N) have been moved as expected to higher frequencies. A1 is found at 1400 Hz (2.92), but A0 now appears as a doublet with the minimum at 710 Hz. The two maxima of this doublet lie at 670 Hz (2.44) and 750 Hz (2.72), respectively. The predicted frequency shift due to the gas exchange would be 2.93 for pure He and 2.56 for He(5N), which is close to the observed values. The exact content of N in the He(5N) cylinder was not known.

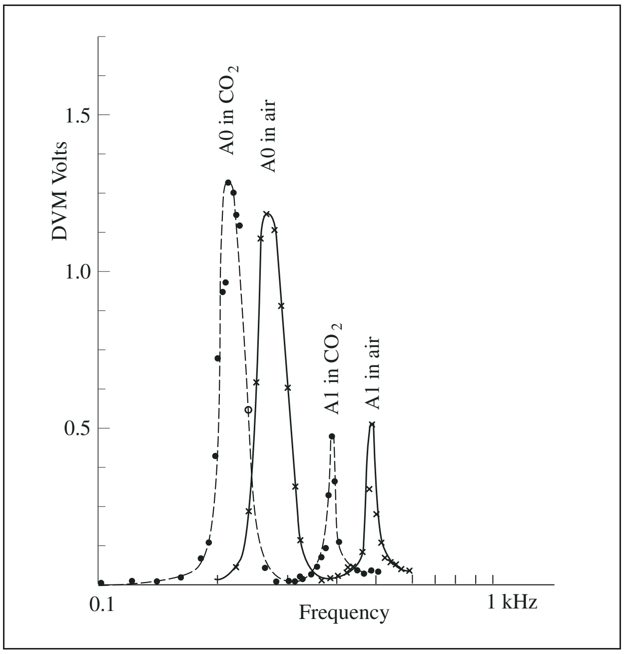

Figure 2. Frequency responses for A0 and A1 in air (crosses) and CO_2 (circles).

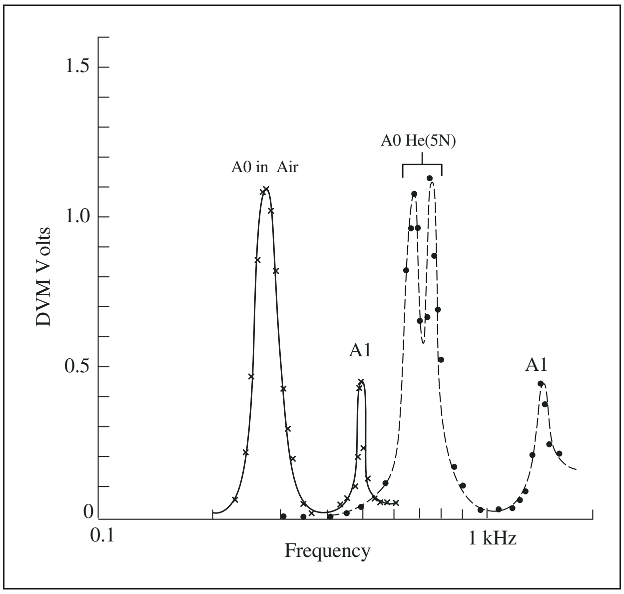

Figure 3. Frequency responses for A0 and A1 in air (crosses) and He(5N) (circles). A doublet is observed for A0 in He(5N).

3.2. Measurements in air/He mixtures

Because of the presence of a doublet for A0 at about 700 Hz in helium, it was decided to investigate the two peaks in mixtures of air and helium, ranging from 80:20% air/ He(5N) to 20/80% in six steps. Results, typical of this study are shown in Figure 4. A progressive rise in mode frequencies is observed as the helium content is increased. It can also be seen that the A1 peak is single in all these trials, while the A0 peak is multiple at all gas mixtures, except for the high air content of 80:20%. The multiple peaks probably indicate interaction with body modes.

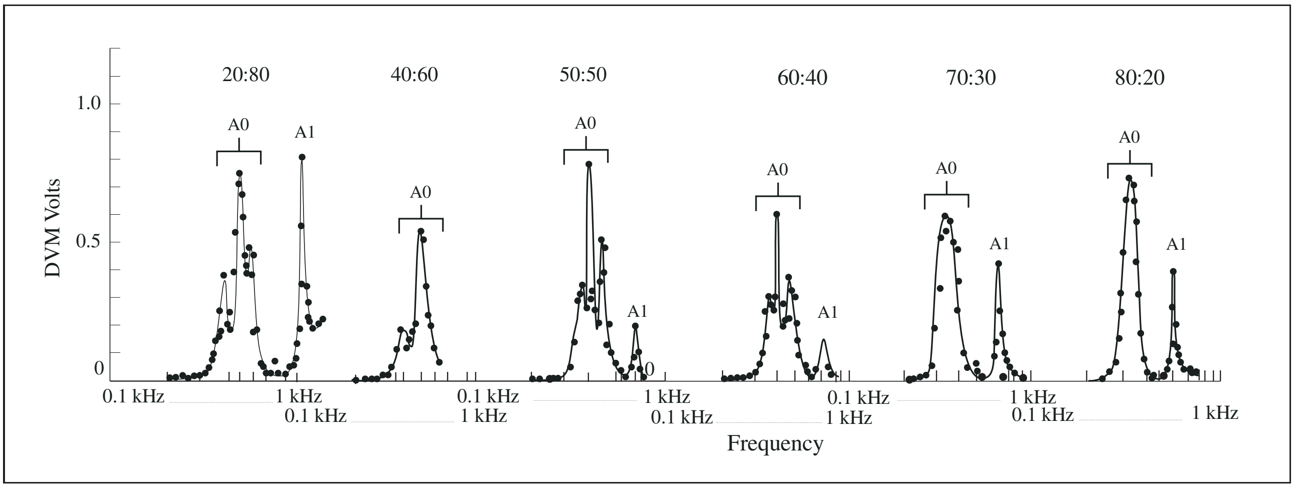

Figure 4. Frequency responses for A0 and A1 in air / He(5N) mixtures, ranging from high helium content (left) to high air content (right). The 40:60% run was interrupted at about 700 Hz so no A1 peak appears. The multiple peaks for A0 suggest interaction with body modes.

The peak frequencies of the measurements in Figure 4 and other determinations have been plotted against gas composition (see Figure 5). Parallel trend lines have been drawn in keeping with the expectations of the frequency shifts in Table I. The measured frequencies agree rather well with predictions. It can also be seen that, for certain gas mixtures, some of the peaks associated with A0 fall close to the frequencies of prominent body modes of the violin used in the experiments. These occur at 425 Hz (probably C2), 480 Hz (T1), 545 Hz (C3) and 700 Hz (probably C4). An interaction between cavity and body modes is thus a likely explanation of the multiple peaks observed in Figures 3 and 4, as the cavity modes are shifted through the frequency range by changing the gas mixture.

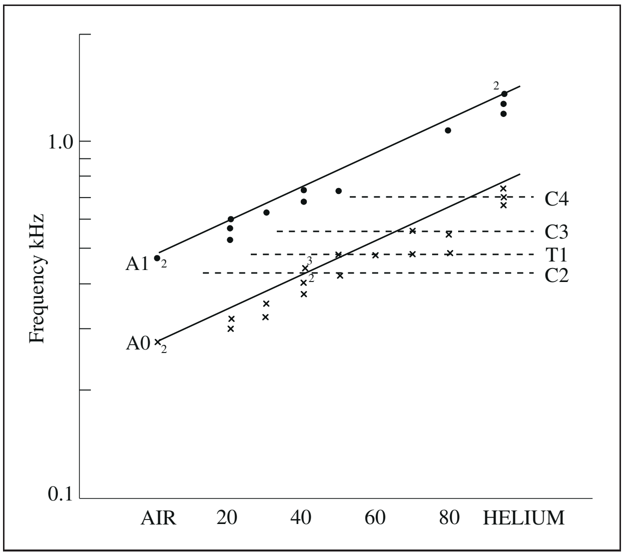

Figure 5. Measured A0 and A1 peak frequencies in air/ He(5N) atmospheres as a function of the He(5N) content in percent. The trend lines show the expected frequency shifts according to Table I. Multiple symbols for certain gas mixtures indicate multiple peaks in the frequency responses. The numbers at some data points refer to identical values obtained in separate runs. The dashed horizontal lines indicate the frequencies of prominent body modes of the violin used in the experiments.

4. Discussion

For the violin used in these experiments, the A0 and A1 peaks in air and CO_2, were single (see Figure 2). The level of excitation in the experiments was rather low. It is not known whether higher levels of excitation would have displayed signs of interaction with some body mode in the vicinity of A1, T1 being closest in frequency. No interaction would be expected near A0, as no body mode falls close in frequency. As discussed below there is no difficulty exciting body modes with A0 in gas mixtures.

In atmospheres containing helium, A1 remained single while A0 was associated with multiple peaks (see Figure 3 and 4). This change can probably be ascribed to interaction with body modes as A0 was raised in frequency. The A0 mode is primarily a "breathing mode" and therefore capable of exciting body modes which radiate a monopole component. The doublet in He(5N) at about 700 Hz in Figure 3 may be a simple case of A0 interacting with body mode C4, which occurs at about the same frequency. In the 60:40 and 50:50 air/He(5N) mixtures there is a peak at 400 Hz with another significant peak at about 450 Hz and 480 Hz, respectively. Here, one might speculate about an interaction between A0 with the a body mode at 425 Hz (most probably C2). The 40:60 air/He(5N) mixture shows a peak at 500 Hz which coincides with the antiresonance between T1 and C3 (these two peaks and the associated antiresonance have been found repeatedly in this violin). For the 20:80 mixture there is a peak at 500 Hz with subsidary peaks at 400 Hz and 560 Hz, indicating a possible excitation of C2 and C3.

Some precaution is needed in interpreting the results from various air/He(5N) mixtures. The gas mixtures were obtained by adjusting cylinder valves after they had been calibrated for the cylinder in use. The actual mixing occurred in the tube leading to the glove bag, and the resulting gas compositions would be only approximate. The level of accuracy might be judged by an inspection of Figure 5, by comparing the expected rise in frequencies (shown by the trend lines) with the measured data points. Further, it was hoped that the trend line for the expected A0 frequencies would help to determine the nature of the interaction in multiple resonance peaks by picking out the peak associated with A0, but the level of accuracy attained did not allow this.

4.1. Conclusions

The most important conclusion to be drawn from this experiment is that A0 and A1 can be studied in isolation, free from possible interaction with body modes, by immersing the violin in atmospheres other than air. A0 can be moved to higher frequencies where interactions can be studied. It is possible that, by controlling the composition of the atmosphere in the glove bag, A0 may be made to interact with a particular body mode. The innovative use of a glove bag offers a tool for making such investigations of the interactions between cavity modes and body modes possible.

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