# Generation of vortices in He II by a powerful thermal pulse

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Damping of a nonlinear second-sound wave as it passes through the track of a powerful thermal pulse, apparently caused by the formation of vortices in He II, is observed. Their presence affects, via the damping, the traveling time of the probing nonlinear wave.

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1. In stationary superfluid helium flows, the critical rates of formation of vortices are of the order of 0.1 cm/s, while it is well known that in experiments on nonlinear acoustics, the rates attained magnitudes of 2 m/s.[1,2] In addition, it was shown in Ref. 2 that the evolution of such waves is described well by Burgers' equation, following directly from two-velocity hydrodynamics. Evidently, this is related to the fact that a finite development time $\tau_c$, which was not attained in Refs. 1 and 2, is necessary for the formation of vortex structures, namely, an array of vortex lines. Vinen, while studying super-

  

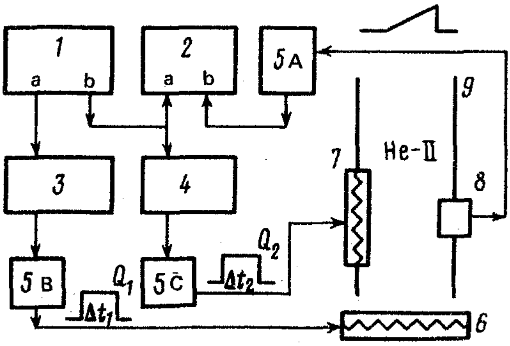


FIG. 1. Experimental setup.

fluid turbulence in stationary flows, studied the problem of the time $\tau_c$ after a constant heat flux was switched on[3]:

$$\tau_c = a Q^{-3/2} . \tag{1}$$

The coefficient $a$ is of the order of 0.1 $W^{3/2}$ s/cm$^3$ and depends on temperature and (weakly) on the geometry of the channel and $Q$ [W/cm$^2$] is the heat-flux density. This relation is valid for flows beginning with the critical density $10^{-3}$ W/cm$^2$ up to $10^{-1}$ W/cm$^2$. Extrapolating $Q$ up to 100 W/cm$^2$ gives a value of $10^{-4}$ s for $\tau_c$, i.e., the value attainable in experiments on nonlinear acoustics. It may be expected that pulses with such parameters will generate vortices.

In order to discuss and study this phenomenon, we carried out an experiment using Vinen's scheme: The track of a powerful heat pulse passing along the channel was probed by transverse pulses of second sound, forming a nonlinear wave. The presence of vortices in the track leads to additional damping, which, because of the relation between the amplitude of the wave and the velocity of propagation, changes the time it takes for the propagating wave to pass from the emitter to the detector.

2. The experiment was carried out using the following procedure (see Fig. 1). A synchronous pulse formed by the driving generator 1 is fed from the output "a" to generator 3; the rectangular signal formed in 3, after amplification in amplifier 5B enters the film emitter 6, exciting the first heat pulse with duration $\Delta t_1$ and power $Q_1$, propagating

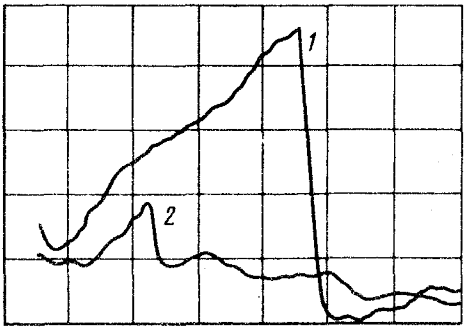


FIG. 2. Oscilloscope traces of the probing wave.

TABLE I.

| $\Delta t_1$ | $Q_1$, W/cm$^2$ | | | | | | |
|---|---|---|---|---|---|---|---|
| μs | 2.9 | 6.6 | 11.8 | 26.6 | 47.3 | 73.8 | 106.3 |
| 10 | – | – | 2013 | 2013 | 2013 | 2013 | 2013 |
| 40 | – | 2012 | 2008 | 1984 | 1970 | 1967 | 1967 |
| 60 | 2012 | – | 1998 | 1966 | 1956 | 1955 | 1956 |
| 80 | 2012 | 2009 | 1995 | 1962 | 1958 | 1957 | 1955 |
| 100 | 2013 | 2006 | 1976 | 1961 | 1954 | 1955 | 1953 |
| 200 | 2012 | 1976 | 1964 | 1954 | 1953 | – | – |
| 500 | 1988 | 1961 | 1958 | 1952 | 1952 | – | – |
| 1000 | 1965 | 1959 | 1955 | – | – | – | – |

along waveguide 9. From output "b" of generator 1, the signal, shifted relative to the signal at "a" by a time $t_{12}$, enters the film emitter 7 through generator 4 and amplifier 5C and excites the second wave with parameters $\Delta t_2$ and $Q_2$, respectively, propagating across the waveguide in the track of the first pulse. Simultaneously, this signal is fed into the input "a", starting the electronic timer 2. The arrival of the transverse wave on the strip thermoresistor of the detector 8 triggers a signal, which, after amplification in 5A, is fed into the input "b", which stops the timer 2. The times $t_{12}$ are chosen so that the waves do not intersect. For the probing pulse, $\Delta t_2 = 20$ μs and $Q_2 = 42$ W/cm$^2$. Both the first and second pulses form a nonlinear second-sound wave with a triangular profile and a

TABLE II.

| $t_{12}$ | $f$, Hz | | | |
|---|---|---|---|---|
| ms | 2 | 1 | 0.5 | 0.2 |
| 4 | 1967 | 1980 | 1990 | 2004 |
| 10 | 1974 | 1989 | 1995 | 2005 |
| 20 | 1976 | 1995 | 1998 | 2010 |
| 40 | 1993 | 2000 | 1999 | 2012 |
| 100 | 2002 | 2005 | 1994 | 2011 |
| 200 | 2006 | 2009 | 2010 | 2015 |
| 400 | 2007 | 2010 | 2010 | 2015 |

break on the trailing or leading edge, depending on the sign of the nonlinearity coefficient $a_2$.[2] The measurements were carried out on the saturation line at a temperature of 2.043 K, maintained to within ±0.2 mK. The arrival of this break at the detector was recorded in the measurements.

3. The results of the measurements are presented in Tables I and II and in Fig. 2. Table I shows the traveling time of the probing signal depending on the intensity $Q_1$ and duration of the heat pulse, $\Delta t_1$. The traveling time $t_2$ of the "probe" in unperturbed helium is 2015 $\mu$s and when the amplitude of the "probe" is decreased, $t_2 \to 1945$ $\mu$s. It is evident from Table I that damping in the track of large-amplitude pulses saturates more quickly [compare with Eq. (1)].

Table II shows the traveling times of the "probe", $t_2$, as a function of $t_{12}$, the time that the "probe" is shifted relative to the pulse, and as a function of $f$, the triggering frequency of the pulse. (In Table I, $t_{12} = 3$ ms, $f = 1$ Hz). The monotonic dependence on $t_{12}$ is clearly evident up to seconds; an experiment in which $f$ is varied confirms that the vortex structure does not disappear for several seconds. The parameters of the first pulse for the data in the table are as follows: $Q_1 = 47$ W/cm$^2$ and $\Delta t_1 = 40$ $\mu$s.

Figure 2 shows oscilloscope traces of the probing pulse, taken at a temperature of 2.043 K. Here, $a_2 = -2$. Oscilloscope trace 1 corresponds to unperturbed helium; oscilloscope trace 2 was taken 3 ms after passage of the pulse with parameters $Q_1 = 90$ W/cm$^2$, and $\Delta t_1 = 50$ $\mu$s. A large decrease in the amplitude of the probe is evident.

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