S1287 Revised Safety Report for beam scheduale 119a

S1287: Direct and indirect measurement of the ^{18}F$(\alpha, p)^{21}$Ne reaction with TUDA

Experiment Leader/Safety Coordinator:
James R. Brown
University of York
York, UK
YO26 4XR
+44 1904 322221
james.brown@york.ac.uk

Local Contact: Lothar Buchmann

1 Description

The experiment will be performed in the ISAC II experimental hall, utilizing the TUDA scattering chamber, filled with H_2 gas at a pressure of 250 Torr. Beam intensities of 1×10^8pps are expected with energies in the region of 70MeV. Hydrogen will be supplied from the gas shack through stainless-steel flammable-gas lines and the flow rate will be limited to 2 litres/minute into atmosphere. The chamber will be separated from the accelerator beam line by a 2.5μm thick, 8mm diameter nickel window mounted on a re-entrant flange (these windows have been shown to hold differential pressure of at least 1atm). We anticipate occasional failure of this window due to beam induced damage (experience suggest that pressure excursions may be detectable prior to a window failure). The presence of the window will require a bypass valve, such that the volume between the window and the first upstream gate valve (IV4) can be evacuated/vented. This valve will be an EPICS controlled remote valve, a Convectron gauge will also be added to this bypass line such that the pressure here can be determined before opening IV4.

Several silicon detectors will be placed within this gas volume along with their associated electronics (pre-amplifiers). These electronics will be cooled by a water coolant system operating at 5–10 °C, in place of the conventional ethanol coolant. The beam will be stopped in a magnetically shielded Faraday cup mounted immediately behind the second detector. We plan to place a pressure relief system on the chamber to relieve pressure build-up in the event of ignition (see section 3.1.1). A diagram of the experimental set up can be seen in figure 1 and a schematic of the gas/vacuum handling system is shown in figure 2.

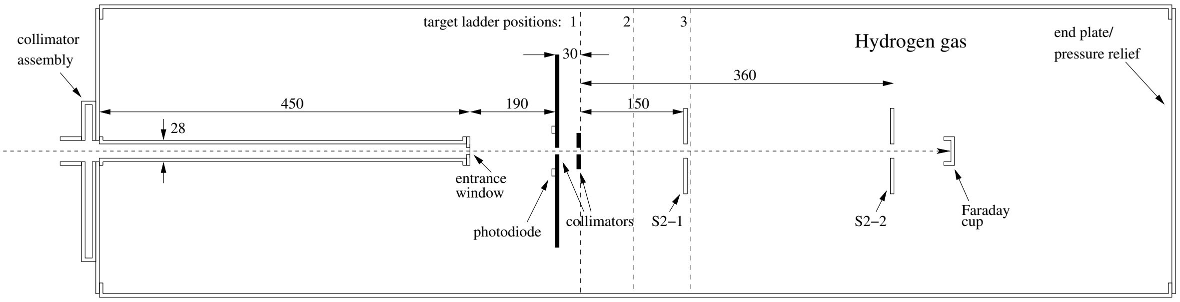

Figure 1: Schematic diagram of the proposed experimental set up.

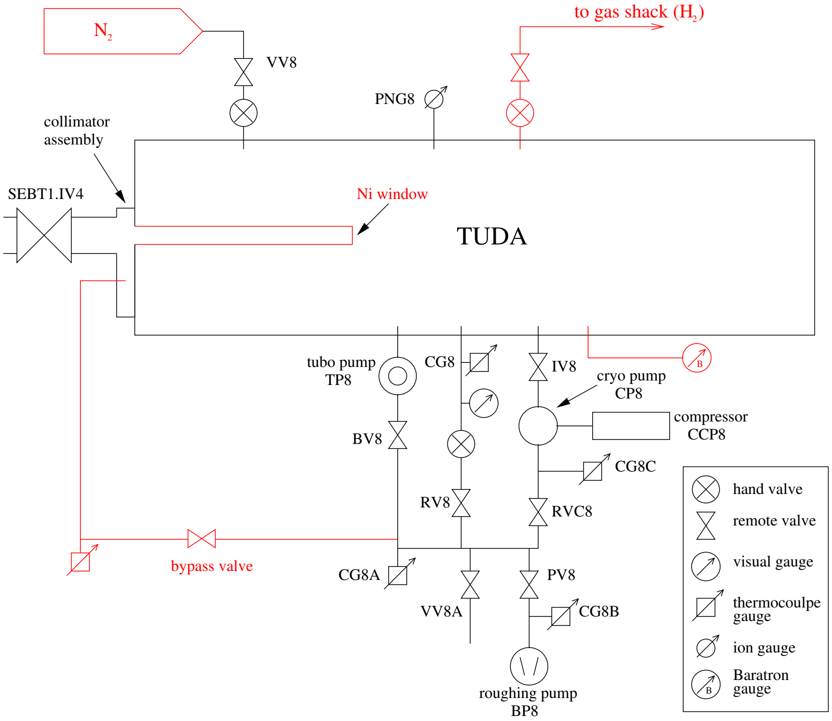

Figure 2: Schematic diagram of the gas/vacuum handling system for TUDA. New elements to be added for this experiment are indicated in red.

2 Definition of Hazards

The dominant hazard in this experiment is the formation and combustion of a flammable gas mixture. The TUDA chamber has an internal volume of ∼195 litres, hence when filled to 250 Torr will contain ∼65 atm-litres of hydrogen (i.e. ∼5 grams). Assuming this is ignited with a stoichiometric mixture of air (approximately 30% H_2 to 70% air—this is approximately the ratio produced if a large leak brought the pressure up to 1 atm), the total chemical energy available is <750kJ [1]. If this were to combust as a deflagration, the flame would propagate with a velocity of the order of 30ms^{-1} [1]. This flame has the potential to ignite other materials, leading to secondary fires. Contained within a stout vessel, the peak pressure reached would be ∼8 atm [1].

For a detonation, the flame speed may be two orders of magnitude higher, and peak pressure ∼4 times larger [4]. However, the detonation induction distance (or run-up, i.e. the distance a deflagration wave must propagate to achieve sufficient pressure build-up to initiate detonation) is estimated to be significantly larger than the TUDA chamber [3].

It should also be noted, as the pressure of the system reduces, eventually a point is reached where flammability is not supported. Edwards' research has proven that it is not possible to sustain a burn in a potentially explosive atmosphere below 60mbar [2].

2.1 Leak Scenarios

Significant hydrogen leaks out of the TUDA chamber are considered unlikely due to the under-pressuring of the chamber. Furthermore, due to the high mobility of H_2 and the frequent air refresh rate within the ISAC II experimental hall (min. every 110 minutes), any such leaks are unlikely to result in a flammable hydrogen/air mixture.

Air ingress into the chamber is a greater concern, either by a slow leak or sudden, fast leak. Leak tests performed by filling the chamber with 200 Torr of air, switching off pumps and monitoring the pressure indicate a leak rate of 1.5 Torr/day (similar tests performed with helium over two days were consistent with this rate). Given the upper flammable limit (UFL) of hydrogen is 75% by volume, in air (at atmospheric pressure, this value is believed to reduce with pressure), in order for a flammable H_2/air mix to form ≥83 Torr of air must leak into the chamber, assuming no loss of H_2. At the observed leak rate, the chamber can be safely operated for at least 7 weeks before a flammable H_2/air mix is produced (N.B. the experimental proposal only requests 10 days of beam time).

Several possibile scenarios leading to a sudden, fast air-leak into the chamber have been identified:

1. failure of a flange plate,
2. damage to the upstream bellows,
3. failure of a valve,
4. damage to the window bypass line,
5. damage to gas lines/connectors,
6. damage to target ladder Conflat connections,
7. failure of the end plate/pressure relief.

Scenarios 1 and 2 are considered highly unlikely due to the robust construction of the TUDA chamber. Each flange plate is constructed from ∼20mm stainless steel and normally secured with at least 14 M8 bolts. The chamber itself is securely fixed to the support platform which forms a stable base (estimate 300–400kg), thus eliminating any risk of damage from knocking into the chamber. Similarly, the stable support of the chamber prevents any mechanical stresses being applied to the bellows.

Regarding scenario 3, the only valves ultimately open to air are in the roughing line. These would require the failure of multiple valves, as well as the roughing pump itself or a ruptured line, in order for air to leak into the chamber, hence is not considered a likely scenario. The hydrogen and nitrogen fill lines will be equipped with both a remote and a manual valve, in series, such that both must fail/be opened in order to allow a leak into the chamber. All the roughing lines and valves are located underneath the TUDA support structure which will act to protect them from external influences. Similarly, the window bypass lines will be routed underneath the chamber, hence scenario 4 is unlikely. Hydrogen and nitrogen lines will enter through the top flange of the chamber. Here, the height of the support structure and chamber drastically reduce the possibility of disturbing these lines/connections, thus mitigating the risks presented by scenarios 5 and 6. Scenario 7 is discussed in section 3.1.1.

In the event of a power failure, all valves close, power supplies into the chamber latch off and activate an alarm upon return of power. Scroll pumps (Varian model 110) close themselves off and do not vent to air, thus loss of power is not considered a potential hazard.

2.2 Sources of Ignition

The energy required to ignite a stoichiometric mixture of hydrogen and air at 1atm is estimated to be 0.02mJ [3] (this increases by an order of magnitude at 333 Torr [5]). Several potential sources of ignition have been identified.

Within the TUDA chamber:

- MSL type S2-500 DSSSDs (130V),
- photodiodes (30V),
- preamplifiers (±15V).
- pressure gauges.

In the beam line:

- pressure gauges (<2V),
- Faraday cups (∼300V).

Various pressure gauges connected to the TUDA chamber operate at moderately increased temperatures, though well below the auto-ignition temperature. Prior to filling the chamber with hydrogen, cables to these gauges (CG8, CG8A/B/C and PNG8) will be unplugged, thus removing any risk of ignition from these devices (see Section 3.4). Faraday cups only have power supplied whilst directly in the beam line, i.e. during beam tuning.

Within the gas exhaust lines, the only potential sources of ignition are the scroll pumps. These pumps can fail in a manner that makes them ignition sources [2]. This is mitigated completely under normal operations as the dry scroll pump is only seeing non-flammable pure hydrogen. In the event of a leak to air, the gas is flushed with nitrogen, not pumped through the scroll pump.

3 Safety Measures

A number of safety measures are proposed in order to minimise the risks and effects of the hazards described above.

3.1 Hardware

1. The conventional preamp ethanol coolant system will be replaced with a water based system operating at 5–10°C.
2. A magnetically shielded Faraday cup will be installed instead of the electrically shielded Faraday cup.
3. Two valves (manual and remote) will be installed on all gas lines entering the chamber to safeguard against failure leading to air ingress.
4. A pressure relief system will be installed (see section 3.1.1).
5. A fast acting valve (FAV) is in place 10m upstream of the wall where the beam line enters the ISAC II hall. The sensor for this device is located at the wall. This device has a response time of $\sim$12ms — cf. time for flame to reach the FAV is $>$250ms (at typical deflagration flame speed). The FAV and other typical vacuum valves will hold 2 atmospheres of pressure.
6. Personal protective equipment (i.e. protective goggles/face visor and ear defenders) will be used by those working on the chamber when H_2 is in use.
7. Flammable materials near the chamber must be limited to essential materials only.
8. Two dry chemical fire extinguishers are located near the TUDA chamber, in the SW and SE corners of the ISAC II hall. A further extinguisher is located in the workshop area.
9. A roped-off exclusion zone will be placed around the chamber.

3.1.1 Pressure Relief

In the event of ignition of a flammable gas mixture within the TUDA chamber a device to relieve pressure in a controlled manner is desirable. We propose utilising the downstream end-plate flange to this end. After filling the chamber with hydrogen up to 250 Torr the securing bolts can be removed, leaving the flange held in place by the external pressure (equivalent to $\sim$870kg). In the event of ignition within the chamber, the pressure rise will push back the end plate, opening an area larger than 1200cm^2.

Tests have shown that the end plate begins to leak at a little over 1atm, thus limiting the peak pressure achieved within the chamber. Sufficient pressure to break the Ni foil entrance window will likely be produced, however the conductance through the re-entrant flange is sufficiently low that upstream gate valves should not see pressure greater than 2atm. The conductance out of the end plate is thought to be sufficient to prevent failure of any other connections. The end-plate is fixed to rails which will confine the direction of travel away from personnel. Placing a sandbag, or similar object, at the end of the rails will help to absorb any impact from the end-plate flange. Aluminium shields will be clamped onto the sides of the chamber, adjacent to the pressure relief flange, in order to reduce the possibility of burning gas exiting the flange being directed into areas occupied by personnel.

The possibility of a rapid leak into the chamber through the end plate (scenario 7) is only likely if the chamber becomes over-pressured as a result of overfilling from either the hydrogen or nitrogen lines. Filling with hydrogen or nitrogen will only be done during venting and filling cycles, during which all ignition sources within the chamber will be switched off and the securing bolts will be in place.

3.2 Interlocks

The pressure within the chamber will be monitored throughout the experiment using an MKS Baratron gauge. As well as providing a measure of the pressure (and hence leak rate) which can be monitored both by experimenters and beam operators, this gauge will provide the trigger for interlocks to make the chamber safe if a predefined pressure is exceeded. This device has two programmable set points with relays, allowing power supplies into the chamber (as itemised in Section 2.2) to be cut and gate valves closed independently of the EPICS/PLC control system.

3.3 Commissioning

Prior to the experiment a commissioning phase will be undertaken to investigate the various features of the system. During this period the interlocks will be tested by initiating pressure rises using an inert gas (e.g. nitrogen, helium). This will enable us to set high/low pressure interlocks to within a tight margin of nominal operational pressure. Throughout these tests, the accelerator will be protected by a gate valve.

3.4 Procedures

1. If experimenters require access to the chamber whilst filled with hydrogen, power supplies will first be shut off.
2. If cup readings are required upstream of the chamber during running, gate valve SEBT1.IV4 must be closed.
3. The manual valve on the roughing line must be kept open to allow remote evacuation of the chamber.
4. Crane operations over the TUDA chamber will be forbidden during the experiment due to the possibility of mechanical damage to TUDA.
5. In order to prevent a flammable mixture forming within the chamber during venting and filling, the following procedures will be followed.

Fill Procedure

- ensure all power supplies off, gate valve closed and bypass valve open,
- pump chamber with roughing, turbo and cryo. pumps until P$< 7 \times 10^{-5}$ Torr,
- flush with nitrogen,
- pump nitrogen with roughing pump until P<200 mTorr,
- monitor pressure to ensure leak rate is within acceptable limits (< 1Torr/hr),
- disconnect cables to TUDA gauges (see Section 2.2),
- close bypass valve,
- fill with hydrogen to operating pressure (250 Torr),
- enable hydrogen interlocks (see below),
- remove end plate flange bolts,

- switch on powers supplies,
- open gate valves (interlock bypass required).

A needle gauge is in place on the chamber (sensitive from 0–1000 Torr and requiring no electricity) which can be used during the filling process.

Vent Procedure

- switch off power supplies and close gate valves,
- pump hydrogen out with roughing pump (<200 mTorr),
- replace end plate flange bolts,
- disable interlocks,
- open bypass valve,
- flush chamber with nitrogen,
- pump out nitrogen with roughing pump (<200 mTorr),
- vent chamber to air.

4 Definition of Responsibilities

The Experiment Leader is responsible for ensuring that during the experiment:

1. there is no unattended operation,
2. there is always two people on shift,
3. everyone on shift is aware of the safety hazards and procedures in place (i.e. has read and understood this report),
4. no procedures (as described in section 3.4) are carried out during night shifts (unless essential to make the chamber safe),
5. tick lists are completed by two people to ensure the procedures described in section 3.4 are observed.

5 Decommissioning or Disposal

No non-standard decommissioning or disposal procedures are required following this experiment.

References

[1] `http://www.gexcon.com/handbook/GEXHBchap4.htm`

[2] `http://www.hazardexonthenet.net/article.aspx?AreaID=4&ArticleID=36695`

[3] `http://www.hysafe.org/download/1196/BRHS_Chap1_V1p2.pdf`

[4] `http://www.gexcon.com/handbook/GEXHBchap6.htm`

[5] H.J. Kim, S.H. Chung and C.H. Sohn, “Numerical Calculation of Minimum Ignition Energy for Hydrogen and Methane Fuels”, Journal of Mechanical Science and Technology, Vol. 18, pp. 838–846, 2004

[6] M.A. Green, “Hydrogen Safety Issues Compared To Safety Issues with Methane and Propane”, Advances in Cryogenic Engineering 51, LBNL-59002, 2005

Appendix: Properties of Hydrogen

Table 1: Physical and chemical properties of hydrogen [3, 6].

Density of gas at NTP$^{(1)}$ (g/cm^3)	8.345×10^{-5}
Stoichiometric fraction in air (vol %)	29.53
Flammability limits in air (vol %)	4 – 75
Minimum ignition energy (mJ)	0.019
Auto-ignition temperature in air (°C)	∼585
Heat of combustion (kJ/g)	135.4
Deflagration pressure ratio (in a confined volume)	8.15
Detonation induction distance (Length/diameter)	∼100

(1) NTP (Normal temperature and pressure): 293 K, 101325 Pa.