Felipe VI, Rey de España

y en su nombre

el Rector de la Universidad de Sevilla

Considerando que, conforme a las disposiciones y circunstancias prevenidas por la legislación vigente,

Don Mario Gómez Ramos

nacido el día 8 de febrero de 1990 en Sevilla, de nacionalidad española,

ha superado los estudios universitarios correspondientes organizados por la Facultad de Física, conforme a un plan de estudios homologado por el Consejo de Universidades, con la calificación final de PREMIO EXTRAORDINARIO, y obtuvo el PRIMER PREMIO NACIONAL DE FIN DE CARRERA DE EDUCACIÓN UNIVERSITARIA, expide el presente título universitario oficial de

Licenciado en Física

con validez en todo el territorio nacional, que faculta al interesado para disfrutar los derechos que a este título otorgan las disposiciones vigentes.

Dado en Sevilla, a 8 de mayo de 2017

El interesado,	El Rector,	La Directora Técnica del Área de Alumnos,
	MIGUEL ÁNGEL CASTRO ARROYO	MARÍA TERESA LUANCO GRACIA

017A-062698

Registro Nacional de Títulos	Código de CENTRO	Registro Universitario de Títulos
2014/012683	41008659	000207920

Este título es un duplicado del expedido con fecha 26 de septiembre de 2014 y se expide para hacer constar la obtención del Premio Extraordinario. El presente título surte efectos plenos desde el 1 de agosto de 2013.

SIGN

UNIVERSIDAD DE SEVILLA

El presente título queda registrado al folio 110

bajo el número 1952 del libro 1 de los de su clase.

Sevilla a, 5 de marzo de 2018

El/La funcionario/a,

CLAVE ALFANUMERICA:	Nº REGISTRO NAL. DE TITULOS:	CODIGO DE CENTRO:	REGISTRO UNIV. DE TITULOS:	NRO. EXP. UNIV.
017A-062698	2014/012683	41008659	000207920	2203949

Reverso del título universitario oficial de Licenciado en Física, expedido el día 8 de mayo de 2017 a favor de Don Mario Gómez Ramos, que superó, en julio de 2013, los estudios conducentes al mencionado título, según un plan de estudios homologado por Acuerdo de 14 de julio de 1998 ("B.O.E." 25-VIII-1998).

Fdo.: ***La Directora Técnica del Área de Alumnos,***

Signe M-03/17

CERTIFICADO ACADÉMICO PERSONAL DE ASIGNATURAS SUPERADAS

DATOS DEL ALUMNO/A:

Nombre y Apellidos: MARIO GOMEZ RAMOS
D.N.I. : 28839143
Fecha de nacimiento:08-02-1990

DATOS DE ACCESO

Acceso a la Universidad: PRUEBAS DE ACCESO A LA UNIVERSIDAD-BACHILLERATO LOGSE
Realizada en: 2007-08-ACJ
Calificación Numérica de PAU: 9,52
Universidad de PAU: Universidad de Sevilla

Plan de estudios: LICENCIADO EN FÍSICA (Plan 98)
Expediente : 1118
Número de secretaria:

D./ Dª. JUAN ANTONIO CABALLERO CARRETERO, Secretario/a de este Centro, CERTIFICA que el alumno con los datos reseñados arriba ha obtenido las siguientes calificaciones:
RELACIÓN DE ASIGNATURAS DEL EXPEDIENTE:

Código	Asignatura	Cred	Dur	Tip	Año	Cur	Conv	Agot	Calificación	
7770987	Curso Preliminar de Fundamentos Matemáticos de la Fís	3	L	L	08-09	1	PRI	1	Mat. de Honor	10,0
960001	Métodos Matemáticos de la Física I	12	G1	T	08-09	1	PRI	1	Sobresaliente	10,0
960002	Técnicas Experimentales en Física	6	G1	T	08-09	1	PRI	1	Mat. de Honor	10,0
960003	Física General	15	G1	B	08-09	1	PRI	1	Mat. de Honor	10,0
960004	Análisis Matemático	15	G1	B	08-09	1	PRI	1	Sobresaliente	10,0
960005	Química	6	C1	O	08-09	1	PC1	1	Mat. de Honor	10,0
960006	Programación Científica	6	C2	O	08-09	1	PRI	1	Mat. de Honor	10,0
660003	Alemán I (A1)	8	G1	L	09-10	1	PRI	1	Mat. de Honor	9,5
960007	Mecánica y Ondas	9	G1	T	09-10	2	PRI	1	Mat. de Honor	10,0
960008	Métodos Matemáticos de la Física II	12	G1	T	09-10	2	PRI	1	Mat. de Honor	10,0
960009	Métodos Matemáticos de la Física III	6	C1	T	09-10	2	PC1	1	Sobresaliente	9,5
960010	Técnicas Experimentales I (Mecánica y Ondas, Termodin	6	C1	T	09-10	2	PC1	1	Notable	7,0
960011	Termodinámica	9	G1	T	09-10	2	PRI	1	Mat. de Honor	10,0
960012	Electrónica Básica	9	G1	B	09-10	2	PRI	1	Mat. de Honor	10,0
960013	Dinámica de Sistemas	6	C2	O	09-10	1	PRI	1	Sobresaliente	10,0
960014	Física Térmica	6	C2	O	09-10	1	PRI	1	Mat. de Honor	10,0
660013	Alemán II (A2)	8	G1	L	10-11	3	PRI	1	Mat. de Honor	9,0
960015	Electromagnetismo	9	G1	T	10-11	3	PRI	1	Mat. de Honor	10,0
960016	Física Cuántica	9	G1	T	10-11	3	PRI	1	Mat. de Honor	10,0
960017	Óptica	9	G1	T	10-11	3	PRI	1	Sobresaliente	10,0
960018	Técnicas Experimentales II (Electromagnetismo, Óptica	9	G1	T	10-11	3	PRI	1	Mat. de Honor	10,0
960019	Fundamentos de Física Estadística	6	C1	B	10-11	3	PC1	1	Mat. de Honor	10,0
960020	Física Matemática	12	G1	B	10-11	3	PRI	1	Mat. de Honor	10,0
960022	Física Atómica y Molecular	6	C2	O	10-11	3	PRI	1	Mat. de Honor	10,0
660023	Alemán III (B1)	10	G1	L	11-12	4	PRI	1	Notable	8,7
960024	Electrodinámica Clásica	6	C1	T	11-12	4	PC1	1	Mat. de Honor	10,0
960025	Electrónica	9	G1	T	11-12	4	PRI	1	Mat. de Honor	10,0
960026	Técnicas Experimentales en Electrónica	4,5	C2	T	11-12	4	PRI	1	Mat. de Honor	10,0
960027	Física del Estado Sólido	6	C1	T	11-12	4	PC1	1	Sobresaliente	9,5
960028	Física Estadística	6	C2	T	11-12	4	PRI	1	Sobresaliente	9,3
960029	Mecánica Cuántica	6	C1	T	11-12	4	PC1	1	Sobresaliente	9,3
960030	Técnicas Experimentales en Electrodinámica	4,5	C1	B	11-12	4	PC1	1	Mat. de Honor	10,0
960031	Técnicas Experimentales en Física de Estado Sólido	4,5	C2	B	11-12	4	PRI	1	Mat. de Honor	10,0
960035	Mecánica Cuántica Relativista	6	C2	O	11-12	4	PRI	1	Mat. de Honor	10,0
960036	Física de Medios Continuos	6	C1	O	11-12	4	PC1	1	Sobresaliente	9,0
660033	Alemán IV (B2)	10	G1	L	12-13	1	PRI	1	Notable	8,5
960038	Física Nuclear y de Partículas	6	C1	T	12-13	5	PC1	1	Mat. de Honor	10,0
960039	Mecánica Teórica	6	C1	T	12-13	5	PC1	1	Notable	7,0
960040	Técnicas Experimentales en Física Nuclear	4,5	C2	B	12-13	5	PRI	1	Mat. de Honor	10,0
960045	Dispositivos Electrónicos	6	C2	O	12-13	1	PRI	1	Sobresaliente	9,3
960049	Técnicas Nucleares	6	C1	O	12-13	1	PC1	1	Mat. de Honor	10,0
960050	Teoría Cuántica de Campos	6	C1	O	12-13	1	PC1	1	Sobresaliente	9,0
960052	Física del Plasma	6	C2	O	12-13	1	PRI	1	Sobresaliente	9,0
960053	Cinética Física	6	C1	O	12-13	1	PC1	1	Sobresaliente	10,0
960054	Astrofísica	6	C1	O	12-13	1	PC1	1	Notable	8,8

CERTIFICADO ACADÉMICO PERSONAL DE ASIGNATURAS SUPERADAS

DATOS DEL ALUMNO/A:

Nombre y Apellidos: MARIO GOMEZ RAMOS
D.N.I. : 28839143

Nota Media Expediente (Baremo: 1-4): 3,54
Según Real Decreto 1267/1994, de 10 de junio, por el que se modifica el Real Decreto 1497/1987, de 27 de noviembre, por el que se establecen las directrices generales comunes de los planes de estudios de los títulos universitarios de carácter oficial y diversos Reales Decretos que aprueban las directrices generales propias de los mismos.

Nota Media Expediente (Baremo: 0-10) : 9,68
Según Real Decreto 1125/2003, de 5 de septiembre, por el que se establece el sistema europeo de créditos y el sistema de calificaciones en las titulaciones universitarias de carácter oficial y validez en todo el territorio nacional, aplicando, en su caso, la tabla de conversión aprobada en la Resolución Rectoral de la Universidad de Sevilla de 26/4/2010.

CUADRO RESUMEN DE CRÉDITOS:

Tipo de asignatura		Cred. Requeridos	Cred. conseguidos
LIBRE CONFIGURACIÓN	(L)	33,0	39,0
OBLIGATORIA	(B)	70,5	70,5
OPTATIVA	(O)	72,0	78,0
TRONCAL/FORMACIÓN BÁSIC	(T)	145,5	145,5

LOGROS DEL ALUMNO/A

Convocatoria	Logro Académico obtenido por el Alumno/a.
PRI/2010-11	SUPERADO PRIMER CICLO
PRI/2012-13	LICENCIADO EN FÍSICA

OBSERVACIONES DEL EXPEDIENTE.

EL ALUMNO TERMINÓ DE CURSAR Y SUPERAR LOS CRÉDITOS REQUERIDOS PARA LA TITULACIÓN DE LICENCIADO EN FÍSICA EL 23-07-2013

Y para que así conste, se expide la presente en Sevilla, a 12 de diciembre de 2013 .

VºBº
EL/LA DECANO/DIRECTOR/A

Fdo.: Belén Pérez Verdú

EL/LA SECRETARIO/A

UNIVERSIDAD DE SEVILLA
FACULTAD DE FÍSICA

Fdo.: Juan Antonio Caballero Carretero

EL/LA RESPONSABLE DE ADMINISTRACIÓN DE CENTRO

Fdo.: Adela Machuca Jiménez

Felipe VI, Rey de España

y en su nombre los rectores de

la Universidad Autónoma de Madrid, la Universitat de Barcelona, la Universidad Complutense de Madrid, la Universidad de Granada, la Universidad de Salamanca y la Universidad de Sevilla

Francisco González Lodeiro
El Rector de la Universidad de Granada

Daniel Hernández Ruipérez
El Rector de la Universidad de Salamanca

UNIVERSIDAD AUTÓNOMA DE MADRID

José M. Sanz

José María Sanz Martínez
El Rector de la Universidad Autónoma de Madrid

Dídac Ramírez i Sarrió
El Rector de la Universitat de Barcelona

José Carrillo Menéndez
El Rector de la Universidad Complutense de Madrid

Considerando que, conforme a las disposiciones y circunstancias previstas por la legislación vigente,

Don Mario Gómez Ramos

nacido el día 8 de febrero de 1990 en Sevilla, de nacionalidad española,

ha superado en julio de 2014, los estudios conducentes al TÍTULO oficial de

Máster Universitario en Física Nuclear
por las citadas universidades

establecido por Acuerdo del Consejo de Ministros de 7 de octubre de 2011, expiden el presente título oficial con validez en todo el territorio nacional, que faculta al interesado para disfrutar los derechos que a este título otorgan las disposiciones vigentes.

Dado en Sevilla, a 22 de agosto de 2014

El interesado,	*El Rector,*	*La Directora Técnica del Área de Alumnos,*
	ANTONIO RAMÍREZ DE ARELLANO LÓPEZ	MARÍA TERESA LUANCO GRACIA

017A-030810

Registro Nacional de Títulos	Código de CENTRO	Registro Universitario de Títulos
2014/339890	41008659	215616

SIGNE, S.A.

UNIVERSIDAD DE SEVILLA

El presente título queda registrado al folio .....4.................................
bajo el número ..73...... del libro ....1................ de los de su clase.
....Sevilla..... a, 29... de ...enero............ de ...2016.....

El/La funcionario/a,

CLAVE ALFANUMERICA:	Nº REGISTRO NAL. DE TITULOS:	CODIGO DE CENTRO:	REGISTRO UNIV. DE TITULOS:	NRO. EXP. UNIV.
017A-030810	2014/339890	41008659	215616	2173259

Reverso del Título Oficial de Máster Universitario en Física Nuclear, expedido en Sevilla, el 22 de agosto de 2014 a favor de Don Mario Gómez Ramos, que superó las enseñanzas conducentes al mencionado título.

Fdo.: *La Directora Técnica del Área de Alumnos,*

SIGNE, S.A.

UNIVERSIDAD DE SEVILLA

CERTIFICADO ACADÉMICO

DATOS DEL ALUMNO/A:

Nombre y Apellidos: MARIO GOMEZ RAMOS
NIF: Número de Identificación Fiscal (NIF -DNI): 28839143H

DATOS DE ACCESO

Acceso a la Universidad: LICENCIADO-LICENCIADO EN FÍSICA
Realizada en: 2012-13-ACC
Nota de Admisión en la Titulación: 8,29

DATOS DE LA TITULACIÓN:

Centro: Facultad de Física
Enseñanza: Máster Universitario Oficial
Plan de estudios: (M082) - Máster Universitario en Física Nuclear
Fecha de publicación en el BOE: 02 de Noviembre de 2011
Rama: Ciencias
Expediente: 23
Número de Secretaría:

D./ Dª. JOAQUÍN RAMÍREZ RICO, Secretario/a de este Centro, CERTIFICA, según se desprende de los antecedentes y documentos que obran en la Secretaría de este Centro, que el alumno con datos reseñados arriba tiene realizados los siguientes estudios:
RELACIÓN DE ASIGNATURAS DEL EXPEDIENTE:

ASIGNATURAS CON CALIFICACIÓN DEFINITIVA

Código	Asignatura	Cred	Dur	Tip	Año	C.ag	Conv	Calificación
CURSO 1								
50820001	Astrofísica Nuclear	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820002	Estructura Nuclear	6	G1	B	13-14	1	PRI	Mat. de Honor 10,00
50820004	Física Hadrónica	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820005	Física Nuclear Aplicada II	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820006	Física Nuclear Experimental	6	G1	B	13-14	1	PRI	Sobresaliente 9,00
50820009	Reacciones Nucleares	6	C1	B	13-14	1	PC1	Mat. de Honor 10,00
50820011	Trabajo Fin de Master	24	I	P	13-14	1	PRI	Mat. de Honor 10,00

ASIGNATURAS EN ÚLTIMA SITUACIÓN

Código	Asignatura	Cred	Dur	Tip	Año	C.ag	Conv	Calificación
CURSO 1								
50820001	Astrofísica Nuclear	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820002	Estructura Nuclear	6	G1	B	13-14	1	PRI	Mat. de Honor 10,00
50820004	Física Hadrónica	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820005	Física Nuclear Aplicada II	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820006	Física Nuclear Experimental	6	G1	B	13-14	1	PRI	Sobresaliente 9,00
50820009	Reacciones Nucleares	6	C1	B	13-14	1	PC1	Mat. de Honor 10,00
50820011	Trabajo Fin de Master	24	I	P	13-14	1	PRI	Mat. de Honor 10,00

ASIGNATURAS CON CALIFICACIÓN DEFINITIVA SUPERADAS

Código	Asignatura	Cred	Dur	Tip	Año	C.ag	Conv	Calificación
CURSO 1								
50820001	Astrofísica Nuclear	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820002	Estructura Nuclear	6	G1	B	13-14	1	PRI	Mat. de Honor 10,00
50820004	Física Hadrónica	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820005	Física Nuclear Aplicada II	6	G1	O	13-14	1	PRI	Sobresaliente 9,00
50820006	Física Nuclear Experimental	6	G1	B	13-14	1	PRI	Sobresaliente 9,00
50820009	Reacciones Nucleares	6	C1	B	13-14	1	PC1	Mat. de Honor 10,00
50820011	Trabajo Fin de Master	24	I	P	13-14	1	PRI	Mat. de Honor 10,00

Nota Media Expediente (Baremo: 1-4): 3,6

Según Real Decreto 1267/1994, de 10 de junio, por el que se modifica el Real Decreto 1497/1987, de 27 de noviembre, por el que se establecen las directrices generales comunes de los planes de estudios de los títulos universitarios de carácter oficial y diversos Reales Decretos que aprueban las directrices generales propias de los mismos.

UNIVERSIDAD DE SEVILLA

CERTIFICADO ACADÉMICO

DATOS DEL ALUMNO/A:

Nombre y Apellidos: MARIO GOMEZ RAMOS
NIF: Número de Identificación Fiscal (NIF -DNI): 28839143H

Nota Media Expediente (Baremo: 0-10) : 9,6
Según Real Decreto 1125/2003, de 5 de septiembre, por el que se establece el sistema europeo de créditos y el sistema de calificaciones en la titulaciones universitarias de carácter oficial y validez en todo el territorio nacional, aplicando, en su caso, la tabla de conversión aprobada en la Resolución Rectoral de la Universidad de Sevilla de 26/4/2010.

LOGROS DEL ESTUDIANTE

LOGROS DEL ALUMNO/A

Convocatoria Logro Académico obtenido por el Alumno/a.

PRI/2013-14 Máster Universitario en Física Nuclear

CUADRO RESUMEN DE CRÉDITOS:

Tipo de asignatura		Cred. Requeridos	Cred. Conseguidos	Cred. pendientes	Cred. matriculados
Obligatoria	(B)	18,00	18,00	0,00	0,00
Optativa	(O)	18,00	18,00	0,00	0,00
Trabajo Fin de Máster	(P)	24,00	24,00	0,00	0,00

DATOS DEL TÍTULO

Fecha de finalización de estudios: 22/07/14
Fecha de abono de los derechos del título: 22/08/2014

UNIVERSIDAD DE SEVILLA FACULTAD DE FÍSICA

OBSERVACIONES DEL EXPEDIENTE

Según consta en los archivos de esta Secretaría, las titulaciones de Grado en Física, Máster en Física Nuclear y Máster en Microelectrónica: Diseño y Aplicaciones de Sistemas Micro/Nanométricos no tienen como último requisito necesario para la obtención del título, según las correspondientes memorias de verificación de sus planes de estudios, la superación del trabajo fin de máster/grado.

Y para que así conste, se expide la presente en Sevilla a 31 de enero de 2019 .

Vº Bº El/La Decano/Director/a	El/La Secretario/a	El/La Responsable de Administración
Fdo.: Antonio José Acosta Jiménez	Fdo.: Joaquín Ramírez Rico	Fdo.: Adela Machuca Jiménez

UNIVERSIDAD DE SEVILLA

CERTIFICADO ACADÉMICO

DATOS DEL ALUMNO/A:

Nombre y Apellidos: MARIO GOMEZ RAMOS
NIF: Número de Identificación Fiscal (NIF -DNI): 28839143H

LEYENDA
Las Materias (Mt) mostradas asociadas a las asignaturas se detallan a continuación:

Las Universidades (Univer.) mostradas indican que la asignatura se ha cursado en la universidad que se detalla:
Tipo: Tipos de asignatura (T-Formación Básica, B-Obligatoria, O-Optativa, E-Prácticas Externas Obligatorias, P-Trabajo Fin De Máster, C-Complementos De Formación). Dur-Duración: Curs-Curso, Con-Convocatoria, Calif: Calificación (NP-No Presentado, SS-Suspenso, AP-Aprobado, NT-Notable, SB-Sobresaliente, M-Matrícula honor. La calificación de No Presentado no agota convocatoria.
*M: Asignatura cursada en un Programa de Movilidad.

EL RECTOR DE LA UNIVERSIDAD DE SEVILLA

POR CVANTO D. MARIO GÓMEZ RAMOS

natural de Sevilla, provincia de Sevilla, nacido el 8 de Febrero de 1990 alumno de la Titulación de Máster Universitario en Física Nuclear impartida en la Facultad de Física ha obtenido Premio Extraordinario de Fin de Estudios, en el Curso Académico de 2013 a 2014, y en la forma prevenida por las disposiciones vigentes; en virtud de las mismas, y para que en todo tiempo conste la aplicación y aprovechamiento que en dicho estudio ha manifestado este distinguido alumno, expido el presente con el sello de esta Universidad y refrendado por la Secretaria General de la misma, en Sevilla a 16 de Marzo de 2015

El Rector,

La Secretaria General,

DIPLOMA de Premio Extraordinario de Fin de Estudios en el título universitario oficial de **MÁSTER UNIVERSITARIO EN FÍSICA NUCLEAR** expedido a favor del alumno D. MARIO GÓMEZ RAMOS

SIGILLUM UNIVERSITATIS LITTERARIAE HISPALENSIS

Registro: 100/2014

Felipe VI, Rey de España

y en su nombre

el Rector de la Universidad de Sevilla

Considerando que, conforme a las disposiciones y circunstancias previstas por la legislación vigente,

Don Mario Gómez Ramos

nacido el día 8 de febrero de 1990 en Sevilla, de nacionalidad española,
ha superado en octubre de 2018, los estudios
conducentes al TÍTULO universitario oficial de

Doctor

por la Universidad de Sevilla

dentro del Programa de Doctorado en Ciencias y Tecnologías Físicas,
establecido por Acuerdo del Consejo de Ministros de 20 de septiembre de 2013,
expide el presente título oficial con validez en todo el territorio nacional,
que faculta al interesado para disfrutar los derechos que a este título
otorgan las disposiciones vigentes.

("cum laude", "Doctorado Internacional")

Dado en Sevilla, a 6 de noviembre de 2018

El interesado, — *El Rector,* — *La Directora Técnica del Área de Alumnos,*

MIGUEL ÁNGEL CASTRO ARROYO — MARÍA TERESA LUANCO GRACIA

017A-083401

Registro Nacional de Títulos	Código de CENTRO	Registro Universitario de Títulos
2019/123696	41015858	267598

SIGNE

UNIVERSIDAD DE SEVILLA

El presente título queda registrado al folio 005

bajo el número 9686 del libro 3 de los de su clase.

Sevilla a, 11 de Diciembre de 2019

El/La funcionario/a,

CLAVE ALFANUMERICA:	Nº REGISTRO NAL. DE TITULOS:	CODIGO DE CENTRO:	REGISTRO UNIV. DE TITULOS:	NRO. EXP. UNIV.
017A-083401	2019/123696	41015858	267598	2226664

Reverso del Título Oficial de Doctor, expedido en Sevilla, el 6 de noviembre de 2018 a favor de Don Mario Gómez Ramos, que superó las enseñanzas conducentes al mencionado título.

Fdo.: *La Directora Técnica del Área de Alumnos.*

Signe M-03/18

HOJA DE SERVICIOS

MARTIN SERRANO VICENTE,

CERTIFICA que los datos que constan a continuación en esta Hoja de servicios a fecha de referencia 30/07/2025, concuerdan con los documentos de carácter oficial, presentados por el interesado y con los registrados en el archivo de esta Universidad.

DATOS PERSONALES

GOMEZ RAMOS, MARIO.
NIF: 28839143H | Nacimiento: 08/02/1990.
N.R.P.: 2883914346 Y002700274 | N.I.P.: 28839143.

CONTRATOS

Tipo contrato	Tipo contrato oficial	F. inicio	F. fin
Contrato Predoctoral (Per.Inv.Pred. Form)	Contrato predoctoral	22/10/2014	21/10/2015
Contrato Predoctoral (Per.Inv.Pred. Form)	Contrato predoctoral	22/10/2015	21/10/2018
Obra o Ser.Deter. Tiem.Completo 37,5 hs	Obra o Servicio Determinado	15/12/2018	04/03/2019
Obra o Ser.Deter. Tiem.Completo 37,5 hs	Obra o Servicio Determinado	01/02/2021	30/04/2022
Prácticas Tiem.Completo 37,5 hs	Form. obtención de Práctica Profesional	01/05/2022	30/04/2025
Interinidad Tiempo Completo	Sustitución persona Trabajadora-Completo	01/05/2025	

SERVICIOS PRESTADOS EN ESTA UNIVERSIDAD

Categoría / Cuerpo / Escala - Puesto/Plaza destino	T. R.	Gr.	Nivel	F. nomb.	F. posesión / inicio	F. cese / F. fin	Jor/ Ded	Sit.
PREDOCTORAL PIF FPU MINISTERIO (Investigador) (1 Años 0 Meses 0 Días)				22/10/2014	22/10/2014	21/10/2015		

Categoría / Cuerpo / Escala - Puesto/Plaza destino	T. R.	Gr.	Nivel	F. nomb.	F. posesión / inicio	F. cese / F. fin	Jor/ Ded	Sit.
PREDOCTORAL FPU MINISTERIO (IN001047) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			22/10/2014	21/10/2015	TC_3 7,5h	AC
PREDOCTORAL PIF FPU MINISTERIO (Investigador) (3 Años 0 Meses 0 Días)				22/10/2015	22/10/2015	21/10/2018		
PREDOCTORAL PIF FPU MINISTERIO (IN001607) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			22/10/2015	21/10/2018	TC_3 7,5h	AC
TITULADO SUPERIOR (Investigador) (0 Años 2 Meses 21 Días)				15/12/2018	15/12/2018	04/03/2019		
TITULADO SUPERIOR(IN003525) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física(I0430I08) / No existe área para esta sección.(8888)	ILI	GI			15/12/2018	04/03/2019	TC_3 7,5h	AC
TALENTO DOCTORES (PID JUNTA ANDALUCÍA) (Investigador) (1 Años 3 Meses 0 Días)				01/02/2021	01/02/2021	30/04/2022		
Talento Doctores (PID Junta Andalucía) (IN004766) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/02/2021	30/04/2022	TC_3 7,5h	AC
CONTRATO JUAN DE LA CIERVA INCORPORACIÓN (Investigador) (3 Años 0 Meses 0 Días)				01/05/2022	01/05/2022	30/04/2025		
Contrato Juan de la Cierva Incorporación (IN005869) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_3 7,5h	AC
Contrato Juan de la Cierva Incorporación (IN005870) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_3 7,5h	AC
Contrato Juan de la Cierva Incorporación (IN005869) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_3 7,5h	AC

Categoría / Cuerpo / Escala - Puesto/Plaza destino	T. R.	Gr.	Nivel	F. nomb.	F. posesión / inicio	F. cese / F. fin	Jor/ Ded	Sit.
Contrato Juan de la Cierva Incorporación (IN005870) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_37,5h	AC
CONTRATO JUAN DE LA CIERVA INCORPORACIÓN (Investigador) (3 Años 0 Meses 0 Días)				01/05/2022	01/05/2022	30/04/2025		
Contrato Juan de la Cierva Incorporación (IN005869) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_37,5h	AC
Contrato Juan de la Cierva Incorporación (IN005870) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_37,5h	AC
Contrato Juan de la Cierva Incorporación (IN005869) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_37,5h	AC
Contrato Juan de la Cierva Incorporación (IN005870) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	ILI	GI			01/05/2022	30/04/2025	TC_37,5h	AC
PROF PERMANENTE LABORAL-MOD PCD INTERINO (0 Años 2 Meses 30 Días)				01/05/2025	01/05/2025			
PROFESOR PERMANENTE LABORAL (DL015200) / Física Atómica, Molecular y Nuclear(I043) - Facultad de Física (I0430I08) / Física Atómica, Molecular y Nuclear(390)	LDE	A			01/05/2025		TC240	AC

Total de servicios en la Universidad: **8 Años 8 Meses 21 Días**

Datos referidos a fecha 30/07/2025, total de servicios reconocidos: **8 Años 8 Meses 21 Días**

TITULACIONES

Titulación	F. expedición	Nivel académico	Equivalencia EQF – N. Meses	Organismo	Oficial	Créditos
Doctor por la Universidad de Sevilla	06/09/2018	Doctor	-	Universidad de Sevilla	Si	

Y para que conste, expido el presente certificado en Sevilla a 30 de julio de 2025.

Secretariado de Formación y Evaluación
Vicerrectorado de Profesorado

RAFAEL PERIÁÑEZ CRISTÓBAL, DIRECTOR DEL SECRETARIADO DE FORMACIÓN Y EVALUACIÓN DE LA UNIVERSIDAD DE SEVILLA

HACE CONSTAR:

Que D/Dª. MARIO GOMEZ RAMOS, con N.I.F. 28839143H, ha participado en el curso LENGUA INGLESA PARA LA ACREDITACIÓN ISE III (2015-16: PRIMERA PARTE), finalizado el 18 de Febrero de 2016, con un total de 60 horas presenciales.

Y para que conste y surta los efectos oportunos, firmo el presente en, Sevilla a 6 de Abril de 2016.

Fdo.: Rafael Periáñez Cristóbal

Certificado nº 65284

Instituto de Ciencias de la Educación

Secretariado de Formación y Evaluación

Vicerrectorado de Profesorado

RAFAEL PERIÁÑEZ CRISTÓBAL, DIRECTOR DEL SECRETARIADO DE FORMACIÓN Y EVALUACIÓN DE LA UNIVERSIDAD DE SEVILLA

HACE CONSTAR:

Que D/Dª. MARIO GOMEZ RAMOS, con N.I.F. 28839143H, ha participado en el curso LENGUA INGLESA PARA LA ACREDITACIÓN ISE III (2015-16: SEGUNDA PARTE), finalizado el 27 de Septiembre de 2016, con un total de 80 horas presenciales.

Y para que conste y surta los efectos oportunos, firmo el presente en, Sevilla a 6 de Octubre de 2016.

UNIVERSIDAD DE SEVILLA
INSTITUTO DE CIENCIAS DE LA EDUCACIÓN

Fdo.: Rafael Periáñez Cristóbal

Certificado nº 67452

Trinity College London

MARIO GÓMEZ RAMOS

is awarded

ISE III
Integrated Skills in English
CEFR Level C1
Level 2 Certificate in ESOL International*

Reading	Distinction	October 2016
Writing	Merit	October 2016
Speaking	Distinction	October 2016
Listening	Distinction	October 2016

Certificate issued 16 November 2016

Sarah Kemp
Chief Executive, Trinity College London

Patron HRH The Duke of Kent KG

D.N.I. nº: 28839143H

*Refers to the National Qualifications Framework in England, Wales and Northern Ireland

TRINITY COLLEGE LONDON

Qualification number: 601/5517/6
Trinity ID: 1-584649133:1-584661289
Candidate number: 1-584661289

Regulated by Ofqual

For more information see http://register.ofqual.gov.uk imus

Instituto de Matemáticas de la Universidad de Sevilla

https://www.imus.us.es/FISMAT15/

Se hace constar que:

Mario Gómez Ramos

ha participado en el congreso

FISMAT 2015

Física y Matemáticas:

Dos caras de una misma moneda (32 horas)

Celebrado en Sevilla, del 29 de junio al 10 de julio de 2015.

Sevilla, 10 de julio de 2015

UNIVERSIDAD DE SEVILLA

Instituto Universitario de Investigación de Matemáticas de la Universidad de Sevilla Antonio de Castro Brzezicki

El Comité Organizador

EUROPEAN CENTRE FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS

ECT* TALENT School
"Few-Body Methods and Nuclear Reactions"
Trento, July 20th – August 07th, 2015

I hereby declare that Mario Gomez Ramos attended the above TALENT School for the period July 20- August 7, 2015.

Yours truly,

Wolfram Weise
ECT* Director

Trento, August 24th, 2015

I-38123 VILLAZZANO TRENTO (TN) - STRADA DELLE TABARELLE, 286 TEL +39 0461 314-721 or 722 - FAX +39 0461 935007 www.ectstar.eu
INSTITUTIONAL MEMBER OF THE EUROPEAN SCIENCE FOUNDATION EXPERT COMMITTEE, NUPECC

PhD Program
CyTF
RD99/2011

UNIVERSIDAD DE SEVILLA
FACULTAD DE FÍSICA

Certificate of Attendance

PhD Program "Ciencias y Tecnologías Físicas"

This is to certify that:

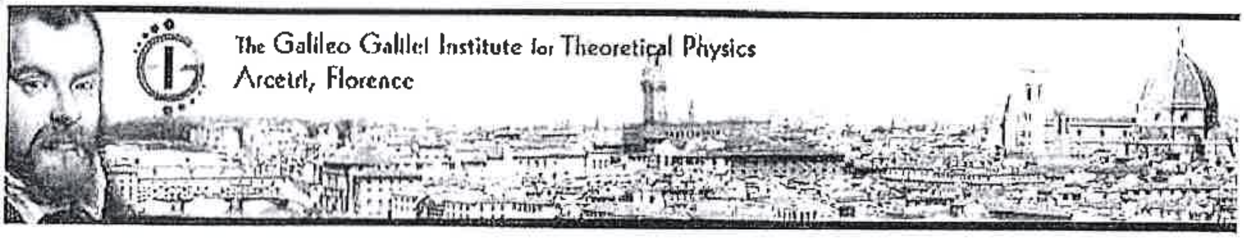
Mr. Gómez Ramos, Mario

Has satisfactorily followed the course below taught by **Dr. Claus Denk** between **14/10/2015** and **16/12/2015** (**20hours lecture**), as part of the training activities of the doctorate program

"Introduction to High-Performance Computing (HPC) with OpenMP and MPI"

UNIVERSIDAD DE SEVILLA
FACULTAD DE FÍSICA

Prof. Ángel Rodríguez Vázquez
PhD Program Coordinator
Ciencias y Tecnologías Físicas



GGI SCHOOLS

Frontiers in Nuclear and Hadronic Physics School

GGI postgraduate school, 22 February-4 March 2016

We certify that ..MARIO GOMEZ - RAMOS...., *has attended the following courses of the 2016 GGI Lectures on* Frontiers in Nuclear and Hadronic Physics School :

The compound nucleus model, resonance states, reactions with clusters.
Alexander Volya (Tallahassee) (10h)
Cluster phenomena in nuclei (structure effects). **Peter Schuck** (Grenoble & Orsay) (6h)
Progress in Strangeness Nuclear Physics, I **Avraham Gal** (Jerusalem) (4h)

The shell model. **Alfredo Poves** (Madrid). (8h)
Heavy Ion Collisions and Nuclear Equation of State. **Pawel Danielewicz** (MSU)(8h)
Progress in Strangeness Nuclear Physics II, **Assumpta Pareno** (Barcellona)(4h).

SEMINARS:

Ivano Lombardo (Università degli Studi di Napoli Federico II and INFN – Sezione di Napoli) - ***"Spectroscopy of Light Nuclei with Low and Medium Energy Nuclear Reactions"***

Catalina Curceanu (LNF-INFN) - ***"Experiments with low-energy kaons at the DAFNE collider in Italy: from strange atoms to strangeness in nuclei and....stars"***

Giovanni Casini and Diego Gruyer (INFN-FI) - ***"Experiments with Heavy-Ions"***

Michele Punturo (INFN-Perugia) - ***"GW150914: the detection of gravitational waves. Results and perspectives"***

Angela Bonaccorso (For the organizers)

UNIVERSIDAD DE SEVILLA

CERTIFICADO DE ACTIVIDADES DOCENTES
1ER Y 2º CICLO / GRADO / MÁSTER

D. MARTÍN SERRANO VICENTE, PROFESOR TITULAR DE UNIVERSIDAD Y SECRETARIO GENERAL DE LA UNIVERSIDAD DE SEVILLA,
CERTIFICA:

Que de acuerdo con la información facilitada por los departamentos responsables de la docencia a través de la aplicación informática diseñada al efecto, el profesor que a continuación se indica ha desempeñado la actividad docente que se especifica a continuación,

Documento: 28839143H

Nombre y Apellidos: D. MARIO GOMEZ RAMOS

CURSO ACA.	PUESTO OCUPADO	ASIGNATURA	TITULACIÓN	CURSO	ACTIVIDAD	N. HORAS	
2015-16	Personal Investigador en Formación	Física Cuántica	Grado en Física / Doble Grado en Física y en Ingeniería de Materiales / Grado en Ingeniería de Materiales	3	LAB	30,00	
	Personal Investigador en Formación	Física	Grado en Óptica y Optometría / Doble Grado en Farmacia y en Óptica y Optometría	1	LAB	30,00	
					TOTAL	**60,00**	
2016-17	Predoctoral PIF FPU Ministerio	Física Cuántica	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales / Grado en Ingeniería de Materiales	3	LAB	30,00	
	Predoctoral PIF FPU Ministerio	Física	Grado en Óptica y Optometría / Doble Grado en Farmacia y en Óptica y Optometría	1	LAB	30,00	
					TOTAL	**60,00**	
2020-21	Talento Doctores (PID Junta Andalucía)	Física Cuántica	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales / Grado en Ingeniería de Materiales	3	LAB	2,50	
	Talento Doctores (PID Junta Andalucía)	Física Cuántica	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales / Grado en Ingeniería de Materiales	3	LAB	7,50	(1)
	Talento Doctores (PID Junta Andalucía)	Física Nuclear y de Partículas	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales	4	XTEOPRA	25,00	
	Talento Doctores (PID Junta Andalucía)	Reacciones Nucleares (USE)	M.U. Erasmus Mundus en Física Nuclear (USE-UAM-UCM-UB-UCBN-SDP-SCAT)	1	XTEOPRA	6,00	(1)
					TOTAL	**41,00**	
2021-22	Contrato Juan de la Cierva Incorporación	Física Cuántica	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales / Grado en Ingeniería de Materiales	3	LAB	8,00	
	Contrato Juan de la Cierva Incorporación	Física Cuántica	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales / Grado en Ingeniería de Materiales	3	LAB	10,00	(1)
	Contrato Juan de la Cierva Incorporación	Física Nuclear y de Partículas	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales	4	XTEOPRA	16,00	
	Contrato Juan de la Cierva Incorporación	Trabajo Fin de Grado	Grado en Física	4	DIR	2,50	

UNIVERSIDAD DE SEVILLA

CERTIFICADO DE ACTIVIDADES DOCENTES

1ER Y 2º CICLO / GRADO / MÁSTER

Documento: 28839143

Nombre y Apellidos: D. MARIO GOMEZ RAMOS

CURSO ACA.	PUESTO OCUPADO	ASIGNATURA	TITULACIÓN	CURSO	ACTIVIDAD	N. HORAS	
	Contrato Juan de la Cierva Incorporación	Física I	Grado en Ingeniería de Materiales	1	XTEOPRA	15,00	
	Contrato Juan de la Cierva Incorporación	Física I	Grado en Ingeniería de Materiales	1	LAB	15,00	
	Contrato Juan de la Cierva Incorporación	Introducción a las Reacciones Nucleares	Máster Universitario en Física Nuclear por la UAM,UCM,UB,UGR,USAL y la US	1	PINFOR	6,00	
	Contrato Juan de la Cierva Incorporación	Reacciones Nucleares (USE)	M.U. Erasmus Mundus en Física Nuclear (USE-UAM-UCM-UB-UCBN-SDP-SCAT)	1	XTEOPRA	6,00	(1)
					TOTAL	**78,50**	
2022-23	Contrato Juan de la Cierva Incorporación	Física Nuclear y de Partículas	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales	4	XTEOPRA	36,50	
	Contrato Juan de la Cierva Incorporación	Trabajo Fin de Grado	Grado en Física	4	DIR	7,50	
	Contrato Juan de la Cierva Incorporación	Física I	Grado en Ingeniería de Materiales	1	XTEOPRA	15,00	
	Contrato Juan de la Cierva Incorporación	Física I	Grado en Ingeniería de Materiales	1	LAB	9,00	
	Contrato Juan de la Cierva Incorporación	Introducción a las Reacciones Nucleares	Máster Universitario en Física Nuclear por la UAM,UCM,UB,UGR,USAL y la US	1	PINFOR	6,00	
	Contrato Juan de la Cierva Incorporación	Reacciones Nucleares (USE)	M.U. Erasmus Mundus en Física Nuclear (USE-UAM-UCM-UB-UCBN-SDP-SCAT)	1	XTEOPRA	3,00	(1)
	Contrato Juan de la Cierva Incorporación	Reacciones Nucleares (USE)	M.U. Erasmus Mundus en Física Nuclear (USE-UAM-UCM-UB-UCBN-SDP-SCAT)	1	PINFOR	3,00	(1)
					TOTAL	**80,00**	
2023-24	Contrato Juan de la Cierva Incorporación	Física Nuclear y de Partículas	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales	4	XTEOPRA	44,00	
	Contrato Juan de la Cierva Incorporación	Trabajo Fin de Grado	Grado en Física	4	DIR	7,50	
	Contrato Juan de la Cierva Incorporación	Física I	Grado en Ingeniería de Materiales	1	XTEOPRA	15,00	
	Contrato Juan de la Cierva Incorporación	Física I	Grado en Ingeniería de Materiales	1	LAB	9,00	
	Contrato Juan de la Cierva Incorporación	Trabajo Fin de Master	Máster Universitario en Física Nuclear por la UAM,UCM,UB,UGR,USAL y la US	1	DIR	10,60	
	Contrato Juan de la Cierva Incorporación	Introducción a las Reacciones Nucleares	Máster Universitario en Física Nuclear por la UAM,UCM,UB,UGR,USAL y la US	1	PINFOR	6,00	
	Contrato Juan de la Cierva Incorporación	Reacciones Nucleares (USE)	M.U. Erasmus Mundus en Física Nuclear (USE-UAM-UCM-UB-UCBN-SDP-SCAT)	1	XTEOPRA	4,00	(1)
	Contrato Juan de la Cierva Incorporación	Reacciones Nucleares (USE)	M.U. Erasmus Mundus en Física Nuclear (USE-UAM-UCM-UB-UCBN-SDP-SCAT)	1	PINFOR	3,00	(1)

UNIVERSIDAD DE SEVILLA

CERTIFICADO DE ACTIVIDADES DOCENTES
1ER Y 2º CICLO / GRADO / MÁSTER

Documento: 28839143

Nombre y Apellidos: D. MARIO GOMEZ RAMOS

CURSO ACA.	PUESTO OCUPADO	ASIGNATURA	TITULACIÓN	CURSO	ACTIVIDAD	N. HORAS	
					TOTAL	**99,10**	
2024-25	Prof Permanente Laboral-Mod PCD Interino	Física Nuclear y de Partículas	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales	4	XTEOPRA	40,00	
	Prof Permanente Laboral-Mod PCD Interino	Trabajo Fin de Grado	Grado en Física	4	DIR	7,50	
	Prof Permanente Laboral-Mod PCD Interino	Física I	Grado en Ingeniería de Materiales	1	XTEOPRA	15,00	
	Prof Permanente Laboral-Mod PCD Interino	Física I	Grado en Ingeniería de Materiales	1	LAB	9,00	
	Prof Permanente Laboral-Mod PCD Interino	Trabajo Fin de Grado	Doble Grado en Física y en Ingeniería de Materiales	5	DIR	5,00	
	Prof Permanente Laboral-Mod PCD Interino	Introducción a las Reacciones Nucleares	Máster Universitario en Física Nuclear por la UAM,UCM,UB,UGR,USAL y la US	1	PINFOR	6,00	
	Prof Permanente Laboral-Mod PCD Interino	Introducción a las Reacciones Nucleares (USE)	Máster Universitario en Física Nuclear (US-UCM-UB-UCBN-SDP-SCAT) (2024)	1	XTEOPRA	4,00	(1)
	Prof Permanente Laboral-Mod PCD Interino	Introducción a las Reacciones Nucleares (USE)	Máster Universitario en Física Nuclear (US-UCM-UB-UCBN-SDP-SCAT) (2024)	1	PINFOR	3,00	(1)
					TOTAL	**89,50**	
2025-26(*)	Prof Permanente Laboral-Mod PCD Interino	Física Nuclear y de Partículas	Grado en Física / Doble Grado en Física y Matemáticas / Doble Grado en Física y en Ingeniería de Materiales	4	XTEOPRA	30,00	
	Prof Permanente Laboral-Mod PCD Interino	Física I	Grado en Ingeniería de Materiales	1	XTEOPRA	15,00	
	Prof Permanente Laboral-Mod PCD Interino	Física I	Grado en Ingeniería de Materiales	1	LAB	15,00	
	Prof Permanente Laboral-Mod PCD Interino	Introducción a las Reacciones Nucleares (USE)	Máster Universitario en Física Nuclear (US-UCM-UB-UCBN-SDP-SCAT) (2024)	1	XTEOPRA	4,00	(1)
	Prof Permanente Laboral-Mod PCD Interino	Introducción a las Reacciones Nucleares (USE)	Máster Universitario en Física Nuclear (US-UCM-UB-UCBN-SDP-SCAT) (2024)	1	PINFOR	3,00	(1)
					TOTAL	**67,00**	

Nota sobre idiomas:
(1) Grupos impartidos en lengua inglesa

Y, para que así conste, a petición del interesado/a, se extiende la presente certificación en Sevilla, a la fecha del sello.

Notas:

- Las asignaturas optativas no vinculadas a un curso concreto figuran con el curso 0.
- En la columna 'Puesto Ocupado' se indica el último puesto desempeñado durante el curso académico en cuestión.

(*) Docencia programada para el curso 2025-26 Estos datos sólo tendrán carácter definitivo una vez finalizado el curso académico de referencia.

Informe global de los resultados obtenidos en los cuestionarios de satisfacción del estudiantado con la docencia.

Curso 2022-23. Informe Definitivo.

MARIO GOMEZ RAMOS (28839143)
Departamento de Física Atómica, Molecular y Nuclear
Área de Física Atómica, Molecular y Nuclear

El grado de satisfacción con:	Profesor V.M.	Depto V.M.	Área V.M.	Univer V.M.
A.I.1 La información que ofrece el/la profesor/a sobre los objetivos y las actividades docentes (trabajos, prácticas, seminarios...) de la asignatura/práctica.	8,45	8,61	8,57	8,54
A.I.2 El sistema de evaluación propuesto en el proyecto docente de la asignatura/práctica.	8,47	7,87	8,15	8,16
A.I.3 La información que ofrece el/la profesor/a sobre la bibliografía y demás recursos didácticos (materiales desarrollados en la enseñanza virtual, etc.) necesarios para cursar la asignatura/práctica.	8,14	7,97	8,20	8,34
A.I.4 El tiempo que debo dedicar al estudio para poder seguir el programa de la asignatura/práctica (en relación a los créditos de la misma).	8,11	7,77	7,94	7,81
A.I.5 La coordinación con otras asignaturas de la misma titulación.	7,27	7,99	7,84	7,81
A.II.1 El cumplimiento de el/la profesor/a con la planificación establecida en el proyecto docente de la asignatura/práctica (objetivos, sistemas de evaluación, actividades docentes, etc.).	8,93	8,82	8,71	8,83
A.II.2 El clima de trabajo y participación que fomenta el/la profesor/a.	8,60	8,47	8,21	8,62
A.II.3 La metodología y los recursos didácticos utilizados por el/la profesor/a.	7,55	8,11	7,91	8,28
A.II.4 La atención que presta el/la profesor/a a los estudiantes cuando lo necesitan y su orientación para la resolución de dudas	8,88	8,92	8,67	8,86
A.II.5 Los criterios de evaluación empleados por el/la profesor/a para evaluar mi aprendizaje.	8,49	8,05	8,20	8,24
A.II.6 La aplicación de los criterios de evaluación y corrección por el/la profesor/a.	8,25	8,46	8,19	8,43
A.II.7 La organización de las clases.	7,59	8,49	8,14	8,45
A.III.1 El modo con el que su docencia me ayuda a alcanzar los objetivos de la asignatura/práctica.	7,94	8,20	7,93	8,24
A.III.2 El nivel de formación alcanzado en esta asignatura/práctica teniendo en cuenta mis conocimientos previos.	7,98	8,31	8,02	8,20
A.III.3 La claridad en las explicaciones y la forma de transmitir los conocimientos del/de la profesor/a.	7,64	8,44	8,05	8,39
A.III.4 La labor docente desarrollada por el/la profesor/a, en general.	8,16	8,56	8,22	8,62

V.M.: Valor medio ponderado según el número de cuestionarios válidos y según el número de créditos impartidos.

VICERRECTORADO DE PERSONAL DOCENTE E INVESTIGADOR

Informe global de los resultados obtenidos en los cuestionarios de satisfacción del estudiantado con la docencia.
Curso 2023-24. Informe Definitivo.

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El grado de satisfacción con:	Profesor V.M.	Depto V.M.	Área V.M.	Univer V.M.
A.I.1 La información que ofrece el/la profesor/a sobre los objetivos y las actividades docentes (trabajos,prácticas, seminarios...) de la asignatura/práctica.	8,56	8,53	8,69	8,54
A.I.2 El sistema de evaluación propuesto en el proyecto docente de la asignatura/práctica.	8,13	7,93	8,16	8,16
A.I.3 La información que ofrece el/la profesor/a sobre la bibliografía y demás recursos didácticos (materiales desarrollados en la enseñanza virtual, etc.) necesarios para cursar la asignatura/práctica.	8,19	7,86	8,43	8,37
A.I.4 El tiempo que debo dedicar al estudio para poder seguir el programa de la asignatura/práctica (en relación a los créditos de la misma).	7,91	7,76	8,26	7,90
A.I.5 La coordinación con otras asignaturas de la misma titulación.	7,89	7,78	7,99	7,90
A.II.1 El cumplimiento de el/la profesor/a con la planificación establecida en el proyecto docente de la asignatura/práctica (objetivos, sistemas de evaluación, actividades docentes, etc.).	9,00	8,61	8,92	8,82
A.II.2 El clima de trabajo y participación que fomenta el/la profesor/a.	8,39	8,44	8,47	8,61
A.II.3 La metodología y los recursos didácticos utilizados por el/la profesor/a.	7,91	8,06	8,05	8,31
A.II.4 La atención que presta el/la profesor/a a los estudiantes cuando lo necesitan y su orientación para la resolución de dudas	8,79	8,82	8,89	8,83
A.II.5 Los criterios de evaluación empleados por el/la profesor/a para evaluar mi aprendizaje.	8,12	8,15	8,36	8,26
A.II.6 La aplicación de los criterios de evaluación y corrección por el/la profesor/a.	8,39	8,45	8,50	8,44
A.II.7 La organización de las clases.	8,24	8,42	8,47	8,47
A.III.1 El modo con el que su docencia me ayuda a alcanzar los objetivos de la asignatura/práctica.	7,86	8,14	8,23	8,28
A.III.2 El nivel de formación alcanzado en esta asignatura/práctica teniendo en cuenta mis conocimientos previos.	8,31	8,20	8,42	8,26
A.III.3 La claridad en las explicaciones y la forma de transmitir los conocimientos del/de la profesor/a.	7,55	8,28	8,19	8,40
A.III.4 La labor docente desarrollada por el/la profesor/a, en general.	8,12	8,52	8,48	8,61

V.M.: Valor medio ponderado según el número de cuestionarios válidos y según el número de créditos impartidos.

VICERRECTORADO DE PERSONAL DOCENTE E INVESTIGADOR

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Structure of ^{13}Be probed via quasi-free scattering

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ABSTRACT

We present an investigation of the structure of ^{13}Be obtained via a kinematically complete measurement of the (p, pn) reaction in inverse kinematics at 265 MeV/nucleon. The relative energy spectrum of ^{13}Be is compared to Transfer-to-the-Continuum calculations which use as structure inputs the overlaps of the ^{14}Be ground-state wave function, computed in a three-body model, with the unbound states of the ^{13}Be residual nucleus. The key role of neutron p-wave orbital in the interpretation of the low-relative-energy part of the spectrum is discussed.

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Single-particle spectroscopic strength from nucleon transfer reactions with a three-nucleon force contribution

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ABSTRACT

The direct reaction theory widely used to study single-particle spectroscopic strength in nucleon transfer experiments is based on a Hamiltonian with two-nucleon interactions only. We point out that in reactions with a loosely-bound projectile, where clustering and breakup effects are important, an additional three-body force arises due to three-nucleon ($3N$) interaction between two nucleons belonging to different clusters in the projectile and a target nucleon. We study the effects of this force on nucleon transfer in (d,p) and (d,n) reactions on ^{56}Ni, ^{48}Ca, ^{26m}Al and ^{24}O targets at deuteron incident energies between 4 and 40 MeV/nucleon. Deuteron breakup is treated exactly within a continuum discretized coupled-channel approach. It was found that an additional three-body force can noticeably alter the angular distributions at forward angles, with consequences for spectroscopic factors' studies. Additional study of transfer to $2p$ continuum in the ^{25}F$(p,2p)^{24}$O reaction, involving the same overlap function as in the ^{24}O$(d,n)^{25}$F case, revealed that $3N$ force affects the (d,n) and $(p,2p)$ reactions in a similar way, increasing the cross sections and decreasing spectroscopic factors, although its influence at the main peak of $(p,2p)$ is weaker. The angle-integrated cross sections are found to be less sensitive to the 3N force contribution, they increase by less than 20%. Including 3N interactions in nucleon removal reactions makes an essential step towards bringing together nuclear structure theory, where 3N force is routinely used, and nuclear direct reaction theory, based on two-nucleon interactions only.

The spectroscopic strength of nucleon states in atomic nuclei, often associated with spectroscopic factors, is central to our understanding of nuclear structure. Due to its connections with nucleon orbit occupancy [1] it has received enormous attention for the last 60 years from the nuclear structure community. Today, the rapid progress of ab-initio treatments of nuclear structure [2] has enabled spectroscopic factors to be related to realistic forces between nucleons.

Spectroscopic factors are often determined from nucleon transfer and nucleon removal experiments by comparing measured and calculated cross sections. Over the last two decades experimental studies scrutinized spectroscopic factor uncertainties using different reaction probes, at the same time extending significantly the range of studied isotopes thanks to the increased availability of radioactive beams worldwide. The experimental studies revealed that spectroscopic factors can be significantly lower than structure model predictions even for double magic closed shell nuclei [3]. This phenomenon, named “spectroscopic-factor quenching”, occurs because nucleon-nucleon (NN) correlations scatter nucleons beyond the mean-field shell model space. The most puzzling discovery from a remarkable set of data collected over two decades is the quenching dependence on neutron-proton binding asymmetry seen in inverse-kinematic nucleon knockout experiments with ^{9}Be target [4] and the absence of significant asymmetry-dependent quenching in nucleon transfers, such as (p,d) reactions [5–7]. Given that spectroscopic-factor determination heavily relies on reaction theory, the nuclear physics community agrees that nucleon-removal reaction models should be further developed and, in particular, moved towards a better integration and coherent description with modern nuclear structure theories. However, the challenges in this direction are significant.

In this Letter, we present a new step towards integrating nuclear reaction and structure theories by pointing out that analysis of all nucleon transfer and nucleon removal experiments is carried out using distorted-wave-type direct reaction models based on a Hamiltonian with NN interaction only [8]. However, it has been known since the 1950s that the three-nucleon (3N) force is important for the correct description of atomic nuclei. In reactions with

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Investigation of the ground-state spin inversion in the neutron-rich ^{47,49}Cl isotopes

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Onset of collectivity for argon isotopes close to $N = 32$

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Searching for particle-hole cluster bands in ^{8}Be using the ISOLDE Solenoidal Spectrometer

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Abstract. The ^{7}Be$(d, p)^8$Be* reaction was measured in inverse kinematics at a beam energy of 11 MeV/u using the ISOLDE Solenoidal Spectrometer, in order to identify and characterise high-excitation states in ^{8}Be. The spin-parities of many of the states in the 16−20 MeV region can be explained as being particle-hole excitations within a two-centre shell model. The present experiment aims to elucidate the spin parities of higher excited states, > 20 MeV, to assess their candidacy as rotational excitations of the aforementioned particle-hole states. The beam intensity in this experiment was measured using a downstream Micron S1 double-sided silicon strip detector to pick up elastically scattered deuterons. The focus of this paper is to present methods for calculating the beam intensity, which is key for extracting the spectroscopic factors of the measured states. Preliminary excitation spectra are also presented.

1 Introduction

Clues to the underlying α-cluster structure of ^{8}Be have been present ever since the very first accelerator-induced nuclear reactions were measured by Cockroft and Walton [1]. In their seminal paper, *Disintegration of Lithium by Swift Protons*, they observed the capture of a proton by lithium-7, producing two α particles. Since then, the 2α structure of ^{8}Be has become well-established; the rotational band, with 2^+ and 4^+ members at 3.03 and 11.35 MeV, built upon the short-lived ground state, possesses a large moment of inertia commensurate with a dumbell-like 2α structure.

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Investigating the ^{10}Li continuum through ^{9}Li$(d,p)^{10}$Li reactions

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The continuum structure of the unbound system ^{10}Li, inferred from the ^{9}Li$(d,p)^{10}$Li transfer reaction, is reexamined. Experimental data for this reaction, measured at two different energies, are analyzed with the same reaction framework and structure models. It is shown that the seemingly different features observed in the measured excitation energy spectra can be understood as due to the different incident energy and angular range covered by the two experiments. The present results support the persistence of the $N=7$ parity inversion beyond the neutron dripline as well as the splitting of the well-known low-lying p-wave resonance. Furthermore, they provide indirect evidence that most of the $\ell=2$ single-particle strength, including possible $d_{5/2}$ resonances, lies at relatively high excitations energies.

1. Introduction

Understanding the nuclear shell evolution as a function of the proton-neutron asymmetry is one of the major goals in nowadays nuclear physics. Within this broad and ambitious program, the $N=7$ isotopic chain has received much attention both experimentally [1–21] and theoretically [22–30]. The ^{10}Li system represents a prominent member of this chain, due to its peculiar features. First, it is the first unbound $N=7$ isotone, following the weakly-bound ^{11}Be nucleus. Second, several experiments [4,11,31] suggest that its ground state consists of an $\ell=0$ virtual state, followed by a narrow p-wave resonance, whose energy sequence would point toward a persistence of the parity inversion observed in ^{11}Be. Finally, an accurate knowledge of the ^{10}Li system is crucial for a proper understanding of the ^{11}Li nucleus, the archetypal three-body Borromean nucleus.

Despite this interest, and the extensive experimental and theoretical efforts, important questions regarding the structure of ^{10}Li remain unanswered. Due to the non-zero spin of the ^{9}Li *core*, the s-wave and p-wave structures are expected to split into $(1^-,2^-)$ and $(1^+,2^+)$ doublets, respectively. However, these doublets have not yet been clearly identified experimentally. In particular, it is unclear whether the prominent peak observed in several experiments [12,14,20], and identified with the $p_{1/2}$ resonance, corresponds to the centroid of the (unresolved) doublet or just to one of its members, with the other component being pushed at higher excitation energies.

In the case of the $s_{1/2}$ virtual state, the situation is less clear. Experimentally, its presence was inferred from the narrow width of the momentum distribution in one-proton and one-neutron removal experiments of energetic ^{11}Be and ^{11}Li beams on a carbon target [31]. Another experimental evidence came from the measurement of the relative velocity distribution between the ^{9}Li and the neutron resulting from the decay of ^{10}Li produced after the collision of a ^{18}O beam on a ^{9}Be target [4]. This relative velocity was found to peak at zero, which is consistent with an $\ell=0$ configuration for the ^{10}Li ground-state. The search for this virtual state has been also pursued with transfer experiments. For example, the excitation function extracted for the reaction ^{9}Li$(d,p)^{10}$Li measured at $E=2.4$ MeV/u at REX-ISOLDE exhibited an excess of strength at zero energy which was consistent with a virtual state with a (negative) scattering length of the order of 13-24 fm [11]. However, a more recent experiment for the same transfer reaction performed at TRIUMF at a higher incident energy [20] did not show any indication of such near-threshold structure, putting into question its very existence.

The situation regarding the presence of one or more $d_{5/2}$ low-lying resonances is even more controversial. Evidence of such a resonance at $E_r \sim 1.5$ MeV has been reported in a fragmentation experiment of ^{11}Li on ^{12}C performed at GSI [12], and supported by the theoretical analysis of Blanchon et al. [26]. The excitation function extracted from the ^{9}Li$(d,p)^{10}$Li reaction [20] displayed also a small bump at $E_r = 1.5$ MeV, but the theoretical analysis

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Benchmarking Faddeev and transfer-to-the-continuum calculations for (p, pN) reactions

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Background: Nucleon-knockout reactions on proton targets (p, pN) have experienced a renewed interest due to the availability of inverse-kinematics experiments with exotic nuclei. Various theoretical descriptions have been used to describe these reactions, such as the distorted-wave impulse approximation, the Faddeev-type formalism, and the transfer-to-the-continuum method.

Purpose: Our goal is to benchmark the observables computed with the Faddeev and transfer-to-the-continuum formalisms in the intermediate energy regime relevant for the experimental (p, pn) and (p, $2p$) studies.

Method: We analyze the ^{11}Be(p, pn)^{10}Be reaction for different beam energies, binding energies, and orbital quantum numbers with both formalisms to assess their agreement for different observables.

Results: We obtain a good agreement in all cases considered, within ≈10%, when the input potentials are taken consistently and realistically.

Conclusions: The results of this work prove the consistency and accuracy of both methods, setting an indication on the degree of systematic uncertainties applicable when using them to extract spectroscopic information from (p, pN) reactions.

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I. INTRODUCTION

Thanks to the development of radioactive isotope beam facilities, experiments on unstable nuclei in inverse kinematics have allowed us to explore nuclear structure far from the valley of stability. In particular, nucleon-knockout experiments with proton targets (p, pN) have regained popularity thanks to their simple reaction dynamics, their capacity to remove deeply bound nucleons [1–4], and the possibility of exploring very rare isotopes using inverse kinematics.

Their ability to explore single-particle properties for weakly and deeply bound nucleons renders (p, pN) reactions an excellent candidate to clarify the ten-year-long puzzle of the asymmetry dependence of the reduction factors (R_s), ratios between experimental and theoretical cross sections, for one-nucleon removal reactions. This puzzle arose from the systematic study of nucleon knockout reactions on ^{9}Be and ^{12}C targets [5,6], which showed a strong dependence of R_s on the difference between proton and neutron binding energies in the nucleus ΔS. This dependence was not found in similar studies on transfer reactions [7–9], even though very similar nuclear structure descriptions were used for both nucleon knockout and transfer, contradicting the generalized assumption that the R_s factors originate from the limitations of the structure models (usually the small-scale shell model), in particular, their inability to describe short-range correlations [10,11]. This has shed doubt on the description of the reaction mechanism in these reactions, prompting careful analysis of their uncertainties [12,13] and assumptions [14].

Although very recent results of (p, pN) reactions on isotopic chains for oxygen [1,3] and carbon [4] have found a small dependence of the reduction factors on ΔS, in agreement with the transfer results, for these results to be reliable, the accuracy of the description of the reaction must be ascertained. At present, multiple reaction models have been used to describe the (p, pN) process: the distorted-wave impulse approximation (DWIA) was extensively used in the 1960s and 1970s [15,16] and has recently been revisited in quantum-mechanical [3,17] and eikonal [1,4,18] descriptions. The Faddeev-Alt-Grassberger-Sandhas (Faddeev-AGS) [2,19–21] and transfer-to-the-continuum [22–24] formalisms have also been employed for the description of (p, pN) reactions, using very different descriptions to the DWIA approach. Given the variety of descriptions of the (p, pN) reaction, benchmarks between the different formalisms provide a useful assessment of their validity and limitations.

Following a previous benchmark between the DWIA and transfer-to-the-continuum formalisms [25] in this work we present a systematic benchmark between Fadddeev-AGS and transfer-to-the-continuum for the ^{11}Be(p, pn)^{10}Be reaction, analyzing its dependence on multiple parameters, such as optical potentials, beam energy, and the orbital quantum number and binding energy of the removed nucleon. The paper

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significant role. There, Faddeev-AGS calculations can provide more reliable results. Conversely, for heavier nuclei and proton removal, Faddeev-AGS calculations become unfeasible, while transfer-to-the-continuum can approach the computation in this regime.

It should also be mentioned that in the presented calculation, the structure and reaction inputs (bound wave function and optical potentials) have been assumed to be independent. Thanks to the recent development of dispersive optical potentials [35] it is now possible to present a consistent analysis of the nucleon-nucleus interaction at negative and positive energies. The dispersive optical potentials present a nonlocal energy-dependent form. This makes them applicable in the implementation of the Faddeev-AGS equations used in this work, but not for the transfer-to-the-continuum one, which would require an extension to include energy-dependent optical potentials in the coupled-channel calculations.

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Description of the ^{11}Li$(p,d)^{10}$Li transfer reaction using structure overlaps from a full three-body model

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ABSTRACT

Recent data on the differential angular distribution for the transfer reaction ^{11}Li$(p,d)^{10}$Li at $E/A =$ 5.7 MeV in inverse kinematics are analyzed within the DWBA reaction framework, using the overlap functions calculated within a three-body model of ^{11}Li. The weight of the different ^{10}Li configurations in the system's ground state is obtained from the structure calculations unambiguously. The effect of the ^{9}Li spin in the calculated observables is also investigated. We find that, although all the considered models succeed in reproducing the shape of the data, the magnitude is very sensitive to the content of $p_{1/2}$ wave in the ^{11}Li ground-state wave function. Among the considered models, the best agreement with the data is obtained when the ^{11}Li ground state contains a $\sim$31% of $p_{1/2}$ wave in the n–^{9}Li subsystem. Although this model takes into account explicitly the splitting of the 1^+ and 2^+ resonances due to the coupling of the $p_{1/2}$ wave to the $3/2^-$ spin of the core, a similar degree of agreement can be achieved with a model in which the ^{9}Li spin is ignored, provided that it contains a similar p-wave content.

1. Introduction

Halo nuclei have triggered intensive work in the nuclear physics community since their discovery back in the eighties [1,2]. The case of neutron Borromean nuclei, consisting of a compact core plus two valence neutrons [3], keeps being the subject of a considerable amount of experimental and theoretical studies. In these three-body systems, any two-body pair is unbound, which poses a real challenge from the theoretical point of view [4]. Examples of two-neutron halo nuclei are ^{6}He, ^{11}Li, ^{14}Be or ^{22}C. The understanding of their structure requires solid constraints on the neutron unbound binary subsystems, i.e. ^{5}He, ^{10}Li, ^{13}Be or ^{21}C.

Our present understanding of the peculiar properties of these exotic systems largely stems from the analysis of reactions in which these nuclei are part of the colliding systems or appear within some of the reaction products. In the former case, the experiments must be performed in inverse kinematics, and have therefore only become possible since the development of rare isotope beam facilities in the late eighties. Examples of these reactions are nucleon-removal (also named knockout) reactions [5,6], Coulomb dissociation [7], single- and multi-particle transfer and, most recently, quasi-free breakup reactions of the form (p,pn) or $(p,2p)$ [8–11]. The outcomes of these measurements are complementary to one another.

Theoretical works have shown that the structure of two-neutron halo nuclei results from the delicate interplay of several factors, such as the binding effect due to the pairing interaction between the halo neutrons, the coupling to the core collective excitations [12], the effect of Pauli blocking and the role of tensor correlations [13].

In the case of ^{11}Li, many theoretical and experimental efforts have been devoted to understanding its conspicuous structure. This system is bound by only $S_{2n} = 369.15(65)$ keV [14]. Its large spatial extension was first evidenced in the pioneering knockout experiments performed by Tanihata and collaborators [1] using an energetic ^{11}Li beam on a ^{12}C target. The analysis of the momentum distributions from subsequent fragmentation experiments [15–17], including the angular correlations of the fragments [18], revealed an admixture of s and p waves in the ^{11}Li ground-state and permitted to extract their relative weights. Reaction cross section data of these high-energy experiments have been also used to constrain the radius and s-wave content of the ^{11}Li ground state [19,20].

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Linking structure and dynamics in (p, pn) reactions with Borromean nuclei: The ^{11}Li$(p, pn)^{10}$Li case

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ABSTRACT

One-neutron removal (p, pn) reactions induced by two-neutron Borromean nuclei are studied within a Transfer-to-the-Continuum (TC) reaction framework, which incorporates the three-body character of the incident nucleus. The relative energy distribution of the residual unbound two-body subsystem, which is assumed to retain information on the structure of the original three-body projectile, is computed by evaluating the transition amplitude for different neutron-core final states in the continuum. These transition amplitudes depend on the overlaps between the original three-body ground-state wave function and the two-body continuum states populated in the reaction, thus ensuring a consistent description of the incident and final nuclei. By comparing different ^{11}Li three-body models, it is found that the ^{11}Li$(p, pn)^{10}$Li relative energy spectrum is very sensitive to the position of the $p_{1/2}$ and $s_{1/2}$ states in ^{10}Li and to the partial wave content of these configurations within the ^{11}Li ground-state wave function. The possible presence of a low-lying $d_{5/2}$ resonance is discussed. The coupling of the single particle configurations with the non-zero spin of the ^{9}Li core, which produces a spin-spin splitting of the states, is also studied. Among the considered models, the best agreement with the available data is obtained with a ^{11}Li model that incorporates the actual spin of the core and contains $\sim$31% of $p_{1/2}$-wave content in the n-^{9}Li subsystem, in accord with our previous findings for the ^{11}Li$(p, d)^{10}$Li transfer reaction, and a near-threshold virtual state.

1. Introduction

Two-neutron Borromean nuclei are unique nuclear systems lying at the edge of the neutron drip-line. These are short-lived, weakly bound nuclei, with typically no bound excited states, and whose binary subsystems are unbound. Although some of them, such as ^{6}He and ^{11}Li, had already been identified long ago as products of reactions with stable beams [1,2], it was not until the late eighties that their unusual properties (such as their large size) were realized thanks to the pioneering experiments performed by Tanihata and collaborators [3] using secondary beams of these species and the subsequent theoretical works initiated by Hansen and Jonson [4]. The picture emerging from these studies revealed a very exotic structure, consisting of a relatively compact core surrounded by two loosely bound nucleons forming a dilute halo.

Later works have revealed that this fragile structure arises from a delicate interplay of different effects, such as the pairing interaction between the halo neutrons or the coupling of the motion of these nucleons with tensor and collective excitations of the core (e.g. [5–7]). A quantitative account of all these effects is a challenging theoretical problem and, quite often, different models lead to different (sometimes contradictory) predictions of the structure properties, such as energies and spin-parity assignments.

Experimentally, a successful technique to probe the properties of the neutron-core system is by means of (p, pn) reactions at intermediate energies (above $\sim$100 MeV/nucleon), in which the radioactive beam collides with a proton target, removing one neutron, and leaving an (unbound) residual nucleus, which will eventually decay into a neutron and a core [8,9]. Typically, these experiments measure the relative energy spectrum of this neutron-core system, whose prominent structures are associated with virtual states or resonances. Moreover, if the core is left in an excited state, gamma rays will be also emitted [10]. Angular momentum and spin assignment of these structures is often done by comparing these spectra with the profiles expected in the hypotheti-

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bitrary scaling factors. In particular, the formalism provides double differential cross sections as a function of the scattering angle of the residual two-body system and the relative energy between its constituents.

The model has been applied to the ^{11}Li$(p,pn)^{10}$Li reaction at 280 MeV/A, comparing with available data for the neutron-^{9}Li system relative-energy distribution. Several structure models of ^{11}Li have been compared, differing on the position of the assumed $s_{1/2}$ virtual states and $p_{1/2}$ resonances, and on the inclusion or not of the ^{9}Li spin which, in turn, give rise to different relative weights for these partial waves in the ground state of ^{11}. The calculated reaction observable is found to be very sensitive to these structure properties. Among the considered models, the best agreement with the data is obtained using a ^{11}Li model that incorporates the actual spin of the core and contains $\sim$31% of $p_{1/2}$-wave content in the n-^{9}Li subsystem and a near-threshold virtual state with an effective scattering length of about -29 fm. The agreement stems from the splitting of the $s_{1/2}$ virtual state and the $p_{1/2}$ resonance. This splitting was obtained thanks to a spin-spin interaction in this work, although its actual origin may arise from more complex correlations. Interestingly, this model was found to provide also a good description of the recent ^{11}Li$(p,d)^{10}$Li transfer data measured at TRIUMF.

We have discussed also the possible presence of a low-lying d-wave resonance in ^{10}Li. An overall good agreement with the data can be obtained in the model ignoring the ^{9}Li spin by forcing a $d_{5/2}$ resonance to appear at E_r =1.5 MeV, which also reduces the s-wave content in ^{11}Li. However, in view of other experimental evidences, the agreement might be merely accidental. In fact, such a resonance is not required in the model including the spin of ^{9}Li to achieve a good description of the data. Due to the smearing effect produced by the energy resolution of the experiment, it is clear that further data, more sensitive to higher excitation energies and with better energy resolution, will certainly help in extracting robust conclusions on the $d_{5/2}$ states.

The formalism presented could be applied to study (p,pn) or $(p,2p)$ reactions induced by other three-body nuclei. Calculations of this kind for ^{14}Be, including also the effect of core excitations, are in progress and will be presented elsewhere.

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Binding-energy independence of reduced spectroscopic strengths derived from $(p, 2p)$ and (p, pn) reactions with nitrogen and oxygen isotopes

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"Quenching" factors

A B S T R A C T

A campaign of intermediate energy (300–450 MeV/u) proton-induced nucleon knockout measurements in inverse kinematics has been recently undertaken at the R^{3}B/LAND setup at GSI. We present a systematic theoretical analysis of these data with the aim of studying the quenching of the single-particle strengths and its binding-energy dependence. For that, the measured semi-inclusive $(p, 2p)$ and (p, pn) cross sections are compared with theoretical predictions based on single-particle cross sections derived from a novel coupled-channels formalism and shell-model spectroscopic factors. A systematic reduction of about 20–30% is found, with a very limited dependence on proton–neutron asymmetry.

1. Introduction

The atomic nucleus is a complicated many-body system of strongly correlated fermions. The idea, first proposed by Mayer [1] and Haxel et al. [2], of treating the motion of the nucleons as independent particles moving in a mean-field potential led to a remarkably simple picture, the independent particle shell-model (IPM), whose most notable success is the explanation of magic numbers in terms of main-shell closure.

Not surprisingly, this appealing but highly simplified description of the nucleus has limitations. Beyond mean-field effects lead to deviations of the IPM which manifest as a fragmentation of the single-particle levels and the subsequent depletion of their occupancies. This effect is usually quantified making use of the spectroscopic factor (SF), which is the norm of the overlap between the A and $A-1$ many-body wave functions [3]. The SF is a measure of how well a nucleus A can be described by a single-particle nucleon attached to a $A-1$ *core*. Since the mean-field potential defining the single-particle basis is not unique, the SF are not unique either [4]. Still, they are useful quantities to describe the behavior of nucleons in the nucleus.

Within these model-dependence constraints, SF or, more generally, overlap functions are essential inputs of reaction calculations. Therefore, information about the SF can in principle be obtained by comparing experimental cross sections with theoretical predictions. In general, it has been found that these theoretical cross sections tend to overestimate experimental ones, and it is common to define a reduction or "quenching" factor $R_s = \sigma_{\rm exp}/\sigma_{\rm th}$. Systematic $(e, e'p)$ studies on stable nuclei, as those performed at NIKHEF [5], suggest that the spectroscopic factor of protons in valence orbits are reduced by 30–40% with respect to the IPM prediction. Similar reductions have been found in systematics for different transfer reactions [6].

These studies have been later extended to more asymmetric systems, using heavy-ion knockout reaction experiments at medium energies up to 100 MeV in which a fast-moving projectile nucleus collides with a stable composite nucleus (such as ^{9}Be or ^{12}C) losing a nucleon. The analysis of these reactions with the eikonal reaction theory [7], assuming spectroscopic factors from shell-model calculations, shows also a sizable quenching but, most notably, with a strong isospin dependence, which manifests as a dependence on the difference between separation energies $\Delta S = S_{p(n)} - S_{n(p)}$, for proton (neutron) removal. In particular, it is found that R_s is close to unity for the removal of weakly bound nucleons, whereas it is much smaller than 1 for deeply bound ones. This has been interpreted as an indication of additional correlations, which cannot be described properly by the shell model [8].

However, this marked dependence on ΔS does not seem to be supported by the results obtained with transfer reactions [9–11].

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Transfer induced by core excitation within an extended distorted-wave Born approximation method

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Background: Dynamic core-excitation effects have been found to be of importance in breakup reactions and may be of relevance when obtaining spectroscopic information from transfer reactions.
Purpose: In this paper we extend the distorted-wave Born approximation (DWBA) formalism in order to allow for noncentral components in the core-core term appearing in the transition operator, which allows for dynamic core-excitation effects. Then we study these effects by applying the formalism to different (d,p) reactions.
Methods: The expression of the nonlocal kernels required for the evaluation of the DWBA amplitudes has been extended so as to include noncentral parts in the core-core interaction. The DWBA scattering amplitude is then obtained by solving the corresponding inhomogeneous equation, with the new computed kernels, and the usual outgoing boundary conditions. A new DWBA code has been developed for this purpose.
Results: For ^{10}Be$(d,p)^{11}$Be, core-excitation effects are found to be almost negligible ($<3\%$). The importance of this effect has been found to depend to a large extent on the excitation energy of the core. This has been confirmed in the ^{30}Ne$(d,p)^{31}$Ne case, for which the excitation energy of the first 2^+ state is 0.8 MeV, and the effect of core excitation increases to $\approx 10\%$.
Conclusions: We find dynamic core-excitation effects in transfer reactions to have small contributions to cross sections, in general. However, they should not be neglected, since they may modify the spectroscopic information obtained from these reactions and may become of importance in reactions with nuclei with a core with high deformation and low excitation energy.

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I. INTRODUCTION

Transfer reactions have for decades been one of the main sources of information on the structure of stable and, more recently, also of exotic nuclei. The angular distribution of the outgoing particles produced in these processes is very sensitive to the transferred orbital angular momentum between the projectile and target, whereas the magnitude depends on the product of the initial and final spectroscopic factors (the normalization of the overlap functions in the initial and final nuclei).

Extraction of accurate structure information from these measurements relies on the comparison of the data (often angular distributions) with calculations using a suitable reaction formalism. Traditionally, the analysis of transfer reactions has been carried out in terms of the distorted-wave Born approximation (DWBA). Corrections and improvements of this method have also been used. For example, when the initial or final nuclei contain collective excited states, multistep processes involving excitations and deexcitations among these states can be suitably incorporated within the coupled-channels Born approximation (CCBA) method [1]. Moreover, when one the colliding nuclei is weakly bound, such as in the case of (d,p) reactions, coupling effects to breakup channels can also influence the transfer cross sections and hence the inclusion of these couplings become important. This has been done within the continuum-discretized coupled channels (CDCC) approximation [2–6] or, more simply, within the adiabatic approximation, such as in the adiabatic distorted wave approximation (ADWA) of Johnson and Tandy [7]. More recently, the Alt–Grasberger–Sandhas (AGS) formulation of the Faddeev equations [8,9] has also been successfully applied to transfer reactions (see Ref. [10] for a recent review of these methods).

In a simple picture, a transfer reaction can be modelled in a three-body model, in which a nucleon, or group of nucleons, is transferred from one nucleus to another. For example, a stripping reaction of the form $b(d,p)B$ can be viewed as a process in which the incident deuteron transfers a neutron to the target nucleus b, producing a composite nucleus $B = b + n$ in a given state defined by the relative wave function of neutron and core b. However, this naive interpretation of the transfer process, which is the basis of the DWBA approximation, neglects possible effects derived from the excitation of the

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Interplay of projectile breakup and target excitation in reactions induced by weakly bound nuclei

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Background: Reactions involving weakly bound nuclei require formalisms able to deal with continuum states. The majority of these formalisms struggle to treat collective excitations of the systems involved. For continuum-discretized coupled channels (CDCC), extensions to include target excitation have been developed but have only been applied to a small number of cases.
Purpose: In this work, we reexamine the extension of the CDCC formalism to include target excitation and apply it to a variety of reactions to study the effect of breakup on inelastic cross sections.
Methods: We use a transformed oscillator basis to discretize the continuum of the projectiles in the different reactions and use the extended CDCC method developed in this work to solve the resulting coupled differential equations. A new code has been developed to perform the calculations.
Results: Reactions ^{58}Ni$(d,d)^{58}$Ni*, ^{24}Mg$(d,d)^{24}$Mg*, ^{144}Sm(^{6}Li ,^{6}Li)^{144}Sm*, and ^{9}Be(^{6}Li ,^{6}Li)^{9}Be* are studied. Satisfactory agreement is found between experimental data and extended CDCC calculations.
Conclusions: The studied CDCC method has proven to be an accurate tool to describe target excitation in reactions with weakly bound nuclei. Moderate effects of breakup on inelastic observables are found for the reactions studied. Cross-section magnitudes are not modified much, but angular distributions present smoothing when opposed to calculations without breakup.

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I. INTRODUCTION

Few-body models have been very successful in describing nuclear reactions involving weakly bound nuclei, where breakup probabilities are high and continuum states of these nuclei influence heavily other relevant reaction channels such as elastic scattering. Many models able to deal with these positive-energy states have been developed, such as continuum-discretized coupled channels (CDCC) [1,2], the adiabatic approximation [3,4], Faddeev-AGS equations [5,6], and several semiclassical approximations [7–12].

In most of these models, in particular CDCC, the weakly bound nucleus is considered to be composed of two subsystems, the valence particle and the core, which may be dissociated during the reaction in a breakup process. These subsystems are usually considered to be inert at the energies of interest. This is a good approximation for reactions involving deuterons, which were the origin of many of these models, but it is more questionable for more complex systems. For this reason, extensions to include the collective excitations of the core subsystem have been developed both for CDCC [13,14] and Faddeev-AGS equations [15]. These extensions were able to give proper descriptions of reactions involving weakly bound nuclei with deformed cores such as ^{11}Be [16] and ^{19}C [17].

In general, these models also consider that the target is an inert system without internal degrees of freedom relevant for the reaction. Possible excitations of the target are assumed to be effectively included in the fragment-target optical potentials, rather than explicitly treated. This assumption makes these models unsuitable to describe excitation of the target or more generally any process in which both breakup of one system and collective excitation of the other may take place concurrently.

However, there exist a variety of measurements in which weakly bound nuclei collide with nuclei with collective degrees of freedom which are excited during the reaction, either due to a big deformation and an associated rotational spectrum or to the existence of low-energy vibrational levels [18,19]. These experiments require a consistent description of both breakup and collective excitation of the target if reliable information is to be obtained from them.

Extensions to include target excitation in CDCC were already developed in the 1980s by the Kyushu–Pittsburg groups [20] and have received some recent attention [21] but in general have been restricted to deuteron scattering considering only its s-wave component. Therefore, we find it timely to reexamine the corresponding formalism and apply it to more general reactions using the full formalism without introducing further approximations. In this respect, it must be remarked that the extension of the Faddeev-AGS equations which allowed for the inclusion of collective excitations of the core subsystem also permits the inclusion of target excitation thanks to the symmetric treatment of target and projectile which is employed in the Faddeev equations [15]. In this work we reexamine the extension of the CDCC method to include target excitation. The outline of this work is the following: in Sec. II the formalism used for the extension is presented, while calculations for different low- to medium-energy reactions are shown in Sec. III. Finally, the summary and conclusions are presented in Sec. IV.

II. SCATTERING FRAMEWORK

In this section we derive the expression for the coupling potentials which allow us to treat breakup of the projectile

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Influence of target deformation and deuteron breakup in (d,p) transfer reactions

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Background: The effect of core excitations in transfer reactions of the form $A(d,p)B$ has been reexamined by some recent works by using the Faddeev–Alt–Grassberger–Sandhas reaction formalism. The effect was found to affect significantly the calculated cross sections and to depend strongly and nonlinearly on the incident deuteron energy.
Purpose: Our goal is to investigate these effects within a coupled-channel formulation of the scattering problem which, in addition to being computationally less demanding than the Faddeev counterpart, may help shed some light onto the physical interpretation of the cited effects.
Method: We use an extended version of the continuum-discretized coupled-channel (CDCC) method with explicit inclusion of target excitations within a coupled-channel Born approximation (CDCC-BA) formulation of the transfer transition amplitude. We compare the calculated transfer cross sections with those obtained with an analogous calculation omitting the effect of target excitation. We consider also an adiabatic coupled-channel (ACC) method. Our working example is the ^{10}Be$(d,p)^{11}$Be reaction.
Results: We find that the two considered methods (CDCC-BA and ACC) reproduce fairly well the reported energy dependence of the core excitation effect. The main deviation from the pure three-body model calculation (i.e., omitting core excitations) is found to mostly originate from the destructive interference of the direct one-step transfer and the two-step transfer following target excitation.
Conclusions: The proposed method; namely, the combination of the CDCC method and the CCBA formalism, provides a useful and accurate tool to analyze transfer reactions including explicitly, when needed, the effect of target excitations and projectile breakup. The method could be useful for other transfer reactions induced by weakly bound projectiles, including halo nuclei.

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I. INTRODUCTION

Transfer reactions have been used over the years as spectroscopic tools for extracting spin-parity assignments for nuclear states, spectroscopic strengths of single-particle configurations, and asymptotic normalization coefficients characterizing the tail of overlap functions. Many analyses of transfer reactions resort to the distorted-wave Born approximation (DWBA) method, which can be regarded as the leading term of the Born expansion in terms of a transition potential and assumes that the reaction is dominated by the elastic channel. The effect of nonelastic channels is assumed to be effectively taken into account by the entrance channel optical model potential describing elastic scattering. Furthermore, very often, this optical potential, which would be angular-momentum dependent and nonlocal, is represented through a simple potential parametrization; for instance, of Woods–Saxon form, containing central and possibly, spin-orbit terms. This approach was early recognized to have severe limitations. First, it is not obvious that the effect of nonelastic channels on the calculated transfer cross sections is properly taken into account by the entrance channel optical potential. Furthermore, it is well known that elastic scattering between heavy ions is mostly sensitive to the nuclear surface, whereas the transfer process is sensitive to small separations between the transferred particle and the respective cores to which it is initially or finally bound. Thus, the approximated three-body wave function used in DWBA, consisting of a product of the elastic-scattering optical potential wave function times the projectile and target ground-state wave functions, is not necessarily accurate for the transfer process.

To overcome these shortcomings, appropriate extensions and alternative models have been proposed and applied. These extensions tend to emphasize specific aspects of the reaction dynamics. For example, when collective excitations are relevant, these can be included by means of a coupled-channel description of the entrance and/or exit channels. This is the *coupled-channel Born approximation* (CCBA) [1–4]. For reactions induced by weakly bound nuclei, such as deuterons, breakup channels are known to be important and must therefore be taken into account. This has been done in a number of ways. One of the most widespread approaches is the adiabatic distorted wave approximation (ADWA) method first proposed by Johnson and Soper [5] and later improved by these and other authors [6,7]. The ADWA transition amplitude is formally identical to that appearing in DWBA, allowing its implementation in standard DWBA codes. The adiabatic model frequently provides significant improvements over DWBA for $A(d,p)B$ reactions. A more elaborated way of including the effect of the breakup channels is by means of a continuum-discretized coupled-channel (CDCC) expansion of the $d+A$ three-body wave function [8–11].

For (d,p) reactions on deformed targets, one may anticipate that both projectile breakup and target excitation can play a role

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Benchmarking theoretical formalisms for (p,pn) reactions: The $^{15}C(p,pn)^{14}C$ case

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Background: Proton-induced knockout reactions of the form (p,pN) have experienced a renewed interest in recent years due to the possibility of performing these measurements with rare isotopes, using inverse kinematics. Several theoretical models are being used for the interpretation of these new data, such as the distorted-wave impulse approximation (DWIA), the transition amplitude formulation of the Faddeev equations due to Alt, Grassberger, and Sandhas (FAGS) and, more recently, a coupled-channels method here referred to as transfer-to-the-continuum (TC).
Purpose: Our goal is to compare the momentum distributions calculated with the DWIA and TC models for the same reactions, using whenever possible the same inputs (e.g., distorting potential). A comparison with already published results for the FAGS formalism is performed as well.
Method: We choose the $^{15}C(p,pn)^{14}C$ reaction at an incident energy of 420 MeV/u, which has been previously studied with the FAGS formalism. The knocked-out neutron is assumed to be in a $2s$ single-particle orbital. Longitudinal and transverse momentum distributions are calculated for different assumed separation energies.
Results: For all cases considered, we find a very good agreement between DWIA and TC results. The energy dependence of the distorting optical potentials is found to affect in a modest way the shape and magnitude of the momentum distributions. Moreover, when relativistic kinematics corrections are omitted, our calculations reproduce remarkably well the FAGS result.
Conclusions: The results found in this work provide confidence on the consistency and accuracy of the DWIA and TC models for analyzing momentum distributions for (p,pn) reactions at intermediate energies.

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I. INTRODUCTION

Thanks to the development of radioactive isotope beam technology, experiments on unstable nuclei in inverse kinematics have been made possible. Among them, studies on single-particle structure and its evolution in nuclei away from the stability valley is one of the main subjects of study in present day nuclear physics. Knockout reactions induced by intermediate energy protons have been one of the most successful tools for studying the single-particle nature both of stable and unstable nuclei. The distorted-wave impulse approximation (DWIA) is one of the reaction models which has been successfully applied to the analysis of these reactions [1–6] (for a recent review, see Ref. [7]). Most DWIA applications have been done for exclusive measurements and under *quasifree* scattering conditions. It remains to assess the accuracy of the method for more inclusive observables, such as total nucleon removal cross sections and momentum distributions of the residual heavy fragment. A recent step toward this goal is provided by the eikonal DWIA formalism recently proposed in Ref. [8].

In recent years, the Alt-Grassberger-Sandhas formulation of the Faddeev equations (FAGS) [9,10], which uses a momentum-space representation of the scattering transition amplitude, has been put forward as an alternative for the analysis of these kinds of processes [11–14].

Very recently, another reaction model, referred to as the transfer-to-the-continuum (TC) framework, has been developed and applied to (p,pN) reactions [15,16]. Since these three formalisms are being used to analyze experimental data, it is of timely importance to establish the consistency among them, and understand the limitations and range of validity in each case.

Within the same scope, it has been shown in [11,12] that one can recover the DWIA formalism using a truncated Faddeev multiple-scattering series. However, the DWIA so obtained differs in some aspects from the one commonly used in actual analyses of (p,pN) data, since the latter usually involves additional approximations.

It is therefore essential to make a comparison between these models and, as a first step towards this goal, in this paper we make a benchmark comparison between DWIA, TC, and FAGS, for a given (p,pn) reaction using, whenever possible, the same input ingredients in the calculations.

The content of the paper is as follows. In Sec. II the formulation of the DWIA and the TC formalisms is given. In Sec. III the longitudinal momentum distributions (LMDs) of the $^{15}C(p,pn)^{14}C$ reaction with DWIA an TC are compared, for different separation energies and studying the effect of the energy dependence of the distorting potentials for the emitted nucleons. A comparison with the FAGS transversal momentum distributions (TMDs) published in Ref. [14] is also presented. Finally, the summary is given in Sec. IV.

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Consequently, the inclusion of these relativistic effects will be relevant for the extraction of reliable spectroscopic factors from the analysis of (p,pn) data.

The same calculations shown in Fig. 4(a) but switching off the distorting potential of the incoming and outgoing nucleons are shown in Fig. 4(b) to see clearly the difference arising from a different choice of NN potentials. One can see that the good agreement between TC and FAGS remains in this case.

The TC calculation, omitting relativistic kinematics corrections, is also found to reproduce remarkably well the FAGS calculation reported for this reaction. However, the inclusion of relativistic corrections increases the TC result by ∼30%, which highlights the relevance of these effects for the extraction of spectroscopic information from absolute (p,pN) cross sections.

IV. SUMMARY

Transverse and longitudinal momentum distribution of the residual ^{14}C nucleus produced in the ^{15}C$(p,pn)^{14}$C knockout reaction at an incident energy of 420 MeV/u have been computed and compared using different reaction frameworks, namely, the distorted-wave impulse approximation (DWIA), the transfer-to-the-continuum (TC) method, and the Faddeev-AGS (FAGS) formalism.

The longitudinal momentum distributions evaluated with TC and EI-DWIA are found to be in excellent agreement both in the shape and magnitude. The agreement remains for increasing separation energies of the removed neutron, giving only 0.3%, 0.8%, 1.4% difference at the peak when $S_n = 1.22$ MeV, 5 MeV, 18 MeV, respectively, corroborating the consistency of the two methods for weakly bound and tightly bound systems. We found that the energy dependence of the optical potentials for emitted nucleons, which are not taken into account in TC, gives a minor, although non-negligible effect on knockout cross section.

From this study, we conclude that the DWIA and TC methods can be reliably used to analyze the momentum distributions for (p,pn) cross sections, which are currently being measured by several experimental campaigns. Extensions of the present benchmark to other situations, such as the $(p,2p)$ case or the removal from non s-wave nucleons, are in progress and will be published elsewhere.

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Rapid Communications

Reduced sensitivity of the (d,p) cross sections to the deuteron model beyond the adiabatic approximation

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It has recently been reported [G. W. Bailey *et al.*, Phys. Rev. Lett. **117**, 162502 (2016)] that (d,p) cross sections can be very sensitive to the n-p interactions used in the adiabatic treatment of deuteron breakup with nonlocal nucleon-target optical potentials. To understand to what extent this sensitivity could originate in the inaccuracy of the adiabatic approximation we have developed a leading-order local-equivalent continuum-discretized coupled-channel model that accounts for nonadiabatic effects in the presence of nonlocality of nucleon optical potentials. We have applied our model to the astrophysically relevant reaction ^{26m}Al$(d,p)^{27}$Al using two different n-p potentials associated with the lowest and the highest n-p kinetic energy in the short-range region of their interaction. Our calculations reveal a significant reduction of the sensitivity to the high n-p momenta thus confirming that it is mostly associated with theoretical uncertainties of the adiabatic approximation itself. The nonadiabatic effects in the presence of nonlocality were found to be stronger than those in the case of the local optical potentials. These results argue for extending the analysis of the (d,p) reactions, measured for spectroscopic studies, beyond the adiabatic approximation.

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Introduction. One-nucleon transfer in (d,p) reactions is an important source of information about the single-particle strength in atomic nuclei, quantified by spectroscopic factors and asymptotic normalization coefficients. They are obtained from a comparison of experimental and theoretical cross sections calculated using direct transfer reaction theory and, therefore, are influenced by its uncertainties. The uncertainties arising due to the input optical potentials and the shape of the mean field that binds the transferred neutron have been known for a very long time. Recently, new theoretical uncertainties have been identified in Ref. [1], associated with the n-p interaction used in the adiabatic treatment of deuteron breakup with *nonlocal* nucleon optical potentials. This work studied the ^{26}Al$(d,p)^{27}$Al reaction, measured in [2] to pin down the ^{26}Al destruction by the (p,γ) reactions in novae explosions, and used several deuteron models: Hulthén model [3], AV18 [4], Reid soft core [5], CD-Bonn [6], and the chiral effective field theory at N4LO with five different regulators [7]. All these models produce exactly the same deuteron wave functions ϕ_d and the vertex functions $V_{np}\phi_d$, where V_{np} is the n-p potential, at the n-p separations r larger than than 2 fm. However, the model predictions for these quantities at $0 < r < 2$ fm are very different. This sensitivity to the short-range n-p wave functions (and the corresponding sensitivity to the high n-p momenta) seems puzzling given the relatively low deuteron incoming energies, about 10 MeV, for which the (d,p) calculations have been done in [1]. Such sensitivity may indicate that other important effects, associated with (d,p) reaction mechanisms, are missing in these calculations.

In this paper, we show that most of the sensitivity of the $A(d,p)B$ cross sections to the high n-p momenta goes away when deuteron breakup is treated beyond the adiabatic distorted-wave approximation (ADWA). The latter is based on the dominant term in the Weinberg state expansion of the $A+n+p$ wave function, calculated neglecting the couplings to all the other Weinberg components [8]. In ADWA with local n-A and p-A optical potentials, the adiabatic potential $U_{dA}(R)$, given by the sum $U_{nA}(R)+U_{pA}(R)$ [9], does not depend on the deuteron model. However, the nonlocal adiabatic potential explicitly depends on the average n-p kinetic energy over the (short) range of their interaction, given by the matrix element $\langle T_{np}\rangle_V \equiv \langle\phi_d|V_{np}T_{np}|\phi_d\rangle/\langle\phi_d|V_{np}|\phi_d\rangle$ [1,10–12]. This matrix element is very sensitive to high n-p momenta, which is reflected in the ADWA cross sections.

We choose the continuum-discretized coupled-channel (CDCC) approach [13,14] to treat deuteron breakup in $A(d,p)B$ reactions beyond the adiabatic approximation. The CDCC, developed and used for local nucleon-target optical potentials only, in some cases predicts significantly different cross sections than the ADWA does [15–17]. Extending the CDCC to the case of nonlocal n-A and p-A potentials, in principle, could be done on the basis of the exact nonlocal ADWA formalism of Ref. [12]. However, it would involve time-consuming calculations of nonlocal kernels when the d-wave component in deuteron is included, making the whole task difficult. For this reason, based on ideas of [10,11] we have developed a leading-order local-equivalent CDCC approximation to have a quick assessment of the role of the high n-p momenta in (d,p) reactions. In the ADWA, the leading-order solution deviates from the exact one by about 10% but the sensitivity to the deuteron model is present in both of them in the same proportions [12], which justifies using the leading-order local-equivalent CDCC for our purposes.

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RECENT DEVELOPMENTS FOR THE CALCULATION OF ELASTIC AND NON-ELASTIC BREAKUP OF WEAKLY-BOUND NUCLEI*

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In this contribution, we review some recent theoretical advances for the calculation of breakup cross sections in reactions induced by weakly-bound nuclei.

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1. Introduction

It is well-known that breakup is a major reaction channel in reactions induced by weakly-bound nuclei. The analysis of breakup experiments has provided important structure information on these nuclei, such as spectroscopic factors, separation energies, positions and widths of resonances, and electric responses to the continuum, among others (see, *e.g.* [1]).

For a two-body projectile, the process can be schematically represented as $a+A \to b+x+A$, where a is the projectile nucleus, b and x its constituents, and A the target. When the final state of the three outgoing fragments is fully determined, the reaction is said to be *exclusive*. If, in addition, the three particles are emitted in their ground state, the corresponding cross section is referred to as *elastic breakup* (EBU).

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Review

The art of modeling nuclear reactions with weakly bound nuclei: status and perspectives

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Abstract We give an overview of the theoretical description of nuclear reactions involving weakly-bound nuclei. Some of the more widespread reaction formalisms employed in the analysis of these reactions are briefly introduced, including various recent developments. We put special emphasis on the continuum-discretized coupled-channel (CDCC) method and its extensions to incorporate core and target excitations as well as its application to three-body projectiles. The role of the continuum for one-nucleon transfer reactions is also discussed. The problem of the evaluation of inclusive breakup cross sections is addressed within the Ichimura–Austern–Vincent (IAV) model. Other methods, such as those based on a semiclasical description of the scattering process, are also briefly introduced and some of their applications are discussed and a brief discussion on topics of current interest, such as nucleon-nucleon correlations, uncertainty evaluation and non-locality is presented.

Contents

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Sequential Nature of $(p,3p)$ Two-Proton Knockout from Neutron-Rich Nuclei

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Twenty-one two-proton knockout $(p,3p)$ cross sections were measured from neutron-rich nuclei at ~250 MeV/nucleon in inverse kinematics. The angular distribution of the three emitted protons was determined for the first time, demonstrating that the $(p,3p)$ kinematics are consistent with two sequential proton-proton collisions within the projectile nucleus. Ratios of $(p,3p)$ over $(p,2p)$ inclusive cross sections follow the trend of other many-nucleon removal reactions, further reinforcing the sequential nature of $(p,3p)$ in neutron-rich nuclei.

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Cluster scattering in the non-local model

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Scattering of weakly bound nuclei with a pronounced cluster structure is strongly affected by their breakup. Usually, this mechanism is accounted for in a three-body model with pairwise potentials. The interaction potentials between complex systems are non-local due to the existence of excitation channels and antisymmetrization. However, a common practice is to use local optical potentials in cluster scattering studies. To assess the validity of replacing non-local optical potentials by their local equivalents, we extend the local-equivalent continuum-discretized coupled-channel (LECDCC) approach proposed by us for deuteron scattering in [Phys. Rev. C98, 011601(R) (2018)] to the case of cluster scattering. We consider the case of ^{6}Li + ^{120}Sn at 27 and 60 MeV, and compare the angular distributions and reaction cross sections for elastic and breakup cross sections with those obtained in the standard continuum-discretized coupled-channel (CDCC) method with local equivalents of non-local potentials. We found that while elastic scattering is not significantly affected by non-locality, the breakup observables could be affected by up to 20% depending on kinematical conditions of their observation.

KEYWORDS

three-body model, elastic scattering, breakup, continuum-discretized coupled-channel method, non-localities in optical potential

1 Introduction

The phenomenon of clustering has been known in nuclear physics for a long time. It is present in most light nuclei where two neutrons and two protons gain from gathering into an α-particle [1]. α-clustering also occurs in even–even $N = Z$ nuclei [2]. A special class of clustering, the halo nuclei, has been found around neutron and proton driplines [3]. More generally, clustering can occur in excited nuclear states close to the thresholds of particle emission channels. It influences cross sections of nuclear reactions involving them. Many such reactions are of importance for stellar nucleosynthesis [4], thus contributing much to shaping the world we live in.

Scattering of weakly bound nuclei with a pronounced cluster structure is at the frontier of modern experimental nuclear research [5, 6]. The information obtained from these studies is affected by the choice of theoretical models used to predict and/or analyze the measured observables. It has been known for a long time that theoretical models should include cluster breakup. To account for this important reaction mechanism, the scattering problem is often described in a three-body model with pairwise interactions, which are always chosen to be local. However, the general Feshbach theory states that interactions between complex systems are non-local [7]: they depend on the inter-nuclear separation both before and after collision. Non-locality comes both from removing the target excitation from consideration and from antisymmetrization between nucleons from both the target and projectile. It most naturally emerges in all *ab initio* calculations [8]. Therefore, an assessment

Appendix

Three-body Schrödinger equation in laboratory and centre-of-mass frames

In a fixed frame of reference where experimental cross-sections are measured, the laboratory frame, the Schrödinger equation for the $C_1 + C_2 + A$ wave function $\Psi_{\rm lab}(\boldsymbol{r}_{C_1}, \boldsymbol{r}_{C_2}, \boldsymbol{r}_A)$ of the $C_1 + C_2 + A$ system with non-local $C_1 - A$, $C_2 - A$ and $C_1 - C_2$ interactions is written as

$$
\begin{aligned}
&(T_{C_1} + T_{C_2} + T_A - E_3)\Psi_{\rm lab}(\boldsymbol{r}_{C_1}, \boldsymbol{r}_{C_2}, \boldsymbol{r}_A) = -\int d\boldsymbol{r}'_{C_1}\, d\boldsymbol{r}'_{C_2}\, d\boldsymbol{r}'_A \\
&\times \left[\delta\left(\boldsymbol{r}_{C_2} - \frac{C_1\boldsymbol{r}_{C_1} + A\boldsymbol{r}_A}{A+C_1} - \boldsymbol{r}'_{C_2} + \frac{C_1\boldsymbol{r}'_{C_1} + A\boldsymbol{r}'_A}{A+C_1}\right) V_{C_1A}(\boldsymbol{r}'_{C_1} - \boldsymbol{r}'_A, \boldsymbol{r}_{C_1} - \boldsymbol{r}_A)\right. \\
&+ V_{C_2A}(\boldsymbol{r}'_{C_2} - \boldsymbol{r}'_A, \boldsymbol{r}_{C_2} - \boldsymbol{r}_A)\ \delta\left(\boldsymbol{r}_{C_1} - \frac{C_2\boldsymbol{r}_{C_2} + A\boldsymbol{r}_A}{A+C_2} - \boldsymbol{r}'_{C_1} + \frac{C_1\boldsymbol{r}'_{C_2} + A\boldsymbol{r}'_A}{A+C_2}\right) \\
&\left.+ V_{C_1C_2}(\boldsymbol{r}'_{C_1} - \boldsymbol{r}'_{C_2}, \boldsymbol{r}_{C_1} - \boldsymbol{r}_{C_2})\ \delta\left(\boldsymbol{r}_A - \frac{C_1\boldsymbol{r}_{C_1} + C_2\boldsymbol{r}_{C_2}}{C_1+C_2} - \boldsymbol{r}'_A + \frac{C_1\boldsymbol{r}'_{C_1} + C_2\boldsymbol{r}'_{C_2}}{C_1+C_2}\right)\right] \\
&\times \delta\left(\frac{C_1\boldsymbol{r}_{C_1} + C_2\boldsymbol{r}_{C_2} + A\boldsymbol{r}_A}{A+C_1+C_2} - \frac{C_1\boldsymbol{r}'_{C_1} + C_2\boldsymbol{r}'_{C_2} + A\boldsymbol{r}'_A}{A+C_1+C_2}\right)\Psi_{\rm lab}(\boldsymbol{r}'_{C_1}, \boldsymbol{r}'_{C_2}, \boldsymbol{r}'_A),
\end{aligned}
\tag{25}
$$

where E_3 is the three-body energy in the laboratory system. Separating the centre-of-mass motion,

$$
\Psi_{\rm lab}(\boldsymbol{r}_{C_1}, \boldsymbol{r}_{C_2}, \boldsymbol{r}_A) = \phi_{\rm cm}\left(\frac{C_1\boldsymbol{r}_{C_1} + C_2\boldsymbol{r}_{C_2} + A\boldsymbol{r}_A}{A+C_1+C_2}\right)\Psi\left(\boldsymbol{r}_{C_1} - \boldsymbol{r}_{C_2}, \boldsymbol{r}_A - \frac{C_1\boldsymbol{r}_{C_1} + C_2\boldsymbol{r}_{C_2}}{C_1+C_2}\right),
\tag{26}
$$

then introducing variables

$$
\begin{aligned}
\boldsymbol{r} &= \boldsymbol{r}_{C_1} - \boldsymbol{r}_{C_2}, \\
\boldsymbol{R} &= \frac{C_1\boldsymbol{r}_{C_1} + C_2\boldsymbol{r}_{C_1}}{C_1+C_2} - \boldsymbol{r}_A, \\
\boldsymbol{R}_{\rm cm} &= \frac{C_1\boldsymbol{r}_{C_1} + C_2\boldsymbol{r}_{C_2} + A\boldsymbol{r}_A}{A+C_1+C_2}
\end{aligned}
\tag{27}
$$

and integrating over $\boldsymbol{r}'$ and $\boldsymbol{R}'_{cm}$ in the r.h.s of Eq. (25) we get Eq. (2).

Partial wave decomposition of coupling potentials $U_{ii'}^{(n)}(\boldsymbol{R})$

In the case of non-zero orbital momenta of continuum bins we use, assuming zero spins for clusters C_1 and C_2, we have

$$
\phi_i(a\boldsymbol{y} - b\boldsymbol{s}) = \sqrt{4\pi}\sum_{\lambda_1\lambda_2}\phi^{l_i}_{\lambda_1\lambda_2}(ay, bs)\left[Y_{\lambda_1}(\hat{y}) \times Y_{\lambda_2}(\hat{s})\right]_{l_i m_i}
\tag{28}
$$

Then for spherical optical potentials

$$
\begin{aligned}
U_{ii'}^{(n)}(\boldsymbol{R}) &= 4\pi\sum_c\sum_j \pi_{ii'}^{(c)}\alpha_c^{2n}\sum_{\lambda\lambda_1\lambda_2\lambda'_1}(-)^\lambda Y_{\lambda\mu}(\hat{R})\int_0^\infty dy\, y^2 U_{j,\lambda}^{(c)}(y,R) \\
&\times \int_0^\infty ds\, s^{2+2n}H_j(s)\phi^{l_i}_{\lambda_1\lambda_2}\left(\gamma_c^{-1}y, \frac{1}{2\gamma_c}s\right)\phi^{l'_i}_{\lambda'_1\lambda_2}(\gamma_c^{-1}y, \beta_c s) \\
&\times \sum_{\mu_1\mu_2\mu}(\lambda_1\mu_1\lambda_2\mu_2|l_i m_i)(\lambda'_1\mu'_1\lambda_2\mu_2|l'_i m'_i)(\lambda_1 - \mu_1\lambda'_1\mu'_1|\lambda\mu)(\lambda_1 0\lambda'_1 0|\lambda 0)\frac{\hat{\lambda}_1\hat{\lambda}'_1}{\sqrt{4\pi}\hat{\lambda}}(-)^{\mu_1} \\
&= \sqrt{4\pi}\sum_{\lambda\mu}(\lambda\mu l_i m_i|l'_i m'_i)Y_{\lambda\mu}(\hat{R})\sum_c \pi_{ii'}^{(c)}\alpha_c^{2n}\int_0^\infty dy\, y^2\left[\sum_j U_{j,\lambda}^{(c)}(y,R) f^{n,\lambda}_{(j)l_i l'_i}(y,R)\right],
\end{aligned}
\tag{29}
$$

where

$$
\begin{aligned}
f^{n,\lambda}_{(j)l_i l'_i}(y,R) &= \sum_{\lambda_1\lambda_2\lambda'_1}(-)^{\lambda'_1}\hat{\lambda}_1\hat{\lambda}\hat{l}_i(\lambda_1 0\lambda'_1 0|\lambda 0)W(\lambda\lambda_1 l'_i\lambda_2;\lambda'_1 l_i) \\
&\times \int_0^\infty ds\, s^{2+2n}H_j(s)\phi^{l_i}_{\lambda_1\lambda_2}\left(\gamma_c^{-1}y, \frac{1}{2\gamma_c}s\right)\phi^{l'_i}_{\lambda'_1\lambda_2}(\gamma_c^{-1}y, \beta_c s).
\end{aligned}
\tag{30}
$$

Finally, the radial part of the partial wave decomposition of the continuum bin is

$$
\begin{aligned}
\phi^l_{\lambda_1\lambda_2}(x,y) = \sum_{\Lambda l_x l_y}(-)^{\lambda_2}\sqrt{\frac{(2l+1)!}{(2l_x)!(2l_y)!}}\,(l_x 0\Lambda 0|\lambda_1 0) \\
(l_y 0\Lambda 0|\lambda_2 0)W(\lambda_1\Lambda l l_y; l_x\lambda_2)x^{l_x}y^{l_y}\phi^{(l)}_\Lambda(x,y)
\end{aligned}
\tag{31}
$$

where $l_x + l_y = l$ and

$$
\phi^{(l)}_\Lambda(x,y) = \frac{2\Lambda+1}{2}\int_{-1}^1 d\mu P_\Lambda(\mu)(x^2 - 2\mu xy + y^2)^{-l/2}\phi_l\left(\sqrt{x^2 - 2\mu xy + y^2}\right)
\tag{32}
$$

where $\phi_l(r)$ is the radial part of the continuum bin in the partial wave l. The integration variable s, chosen in (29), uses the short-range nature of $H(s)$, which makes accurate evaluation of (30) easy. Then the integral over dy is similar to a standard CDCC matrix element for which accurate numerical methods are in place.

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Colloquia: COMEX7

Collective core effects and dineutron correlations in three-body nuclei

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Summary. — Two-neutron halo nuclei, such as ^{6}He, ^{11}Li or ^{14}Be, are known to have a marked (core $+ n + n$) three-body character, which is reflected in breakup, transfer or knockout reactions channels in nucleon-nucleon collisions. Their Borromean nature implies that the correlation between the valence halo neutrons is key to understand their properties, and their structure is also linked to spectra of the unbound core $+ n$ systems. Among other phenomena, the role of core collective excitations may be crucial to understand exotic properties such as parity inversion or shell gap quenching in the vicinity of nuclear halos and related systems. In this contribution it is shown that dineutron correlations can be succesfully probed in proton-target knockout reactions, and that core excitation may be an important ingredient for a proper understanding of experimental observations.

1. – Introduction

Nuclei that present a three-body character have attracted particular interest over the past few decades. This is the case of two-neutron halo nuclei, understood as a compact core surrounded by two weakly bound neutrons, which exhibit exotic features in nuclear collisions [1]. A key feture of these systems is that they have a Borromean structure, *i.e.*, the core $+n+n$ system is bound but the binary subsystems are unbound. Examples include ^{11}Li or ^{6}He, but also ^{14}Be, ^{22}C or even ^{29}F [2]. A good understanding of their properties and reaction dynamics requires knowledge of the low-lying spectrum of the unbound core $+ n$ subsystems, which can be populated in breakup, transfer or knockout reactions induced by two-neutron halos (*e.g.*, refs. [3-6]). But it is also clear that the correlation between the halo neutrons, often described in terms of pairing, is crucial to shape the halo physics [7, 8]. A spatially localized correlation of the halo neutrons is

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Reaction Theory and Advanced CDCC

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Abstract. The Continuum-Discretized Coupled-Channels (CDCC) has been successfully employed to describe elastic and breakup of nuclear reactions induced by weakly bound projectiles. In this contribution, we review some other, less widespread applications of the CDCC wavefunction, some of them in combination with other reaction formalisms, which are being currently employed in the analysis of reactions involving three or more fragments in the initial or final state.

1. Introduction: reminder of the CDCC method

The CDCC method was first introduced by G. Rawitscher [1] and later refined and fully implemented by the Pittsburgh-Kyushu collaboration [2,3] to describe the effect of the breakup channels on the elastic scattering of deuterons. Denoting the reaction by $a + A$, with $a = b + x$ (referred hereafter as the *core* and *valence* particles, respectively), the method assumes that the many-body reaction can be reduced to an effective three-body problem described by the effective Hamiltonian

$$H = H_{\mathrm{proj}} + \hat{T}_{\vec{R}} + U_{bA}(\vec{r}_{bA}) + U_{xA}(\vec{r}_{xA}), \tag{1}$$

with $H_{\mathrm{proj}} = \hat{T}_{\vec{r}} + V_{bx}$ the projectile internal Hamiltonian, $\hat{T}_{\vec{r}}$ and $\hat{T}_{\vec{R}}$ are kinetic energy operators, V_{bx} the inter-cluster interaction and U_{bA} and U_{xA} are the core-target and valence-target optical potentials (complex in general) describing the elastic scattering of the corresponding $b + A$ and $x + A$ sub-systems, at the same energy per nucleon of the projectile. In the CDCC method, the three-body wave function of the system is expanded in terms of the eigenstates of the Hamiltonian H_{proj} including both bound and unbound states. Since the latter form a continuum, a procedure of discretization is applied, consisting in approximating this continuum by a finite and discrete set of square-integrable functions. In actual calculations, this continuum must be truncated in excitation energy and limited to a finite number of partial waves ℓ associated to the relative co-ordinate $\vec{r}$. Normalizable states representing the continuum should be obtained for each ℓ, j values. Two main types of discretization methods are commonly used. One is the *the pseudo-state method*, in which the $b+x$ Hamiltonian is diagonalized in a basis of square-integrable functions, such as Gaussians [4] or transformed harmonic oscillator functions [5]. Negative eigenvalues correspond to the bound states of the systems, whereas positive eigenvalues are

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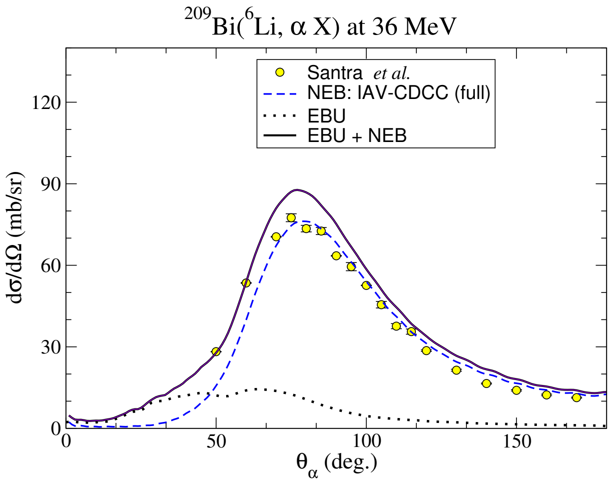

Figure 4. Experimental and calculated α differential cross section resulting from the reaction ^{6}Li+^{209}Bi at 36 MeV. The data from Ref. [35] are compared with calculations for the elastic breakup (EBU) and non-elastic breakup (NEB) components. See text for details.

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Exploring continuum structures in reactions with three-body nuclei

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Abstract. The Transfer to the Continuum method has been applied to describe the ^{11}Li(p,pn) and ^{14}Be(p,pn) reactions in inverse kinematics, using structure overlaps computed within a full three-body model for the projectile. Calculations agree with the available experimental data on the unbound ^{10}Li and ^{13}Be nuclei.

1. Introduction

Nuclear systems at the limit of stability display exotic properties which have motivated extensive theoretical and experimental developments. Light nuclei lying on and beyond the driplines offer a unique enviroment to study nucleon-nucleon correlations and clustering. Among them, the properties of Borromean two-neutron halo nuclei such as ^{6}He, ^{11}Li or ^{14}Be have attracted special interest [1]. In these three-body systems, the loosely bound valence neutrons explore distances far from a compact core, giving rise to a diffuse matter distribution with a strong effect on interaction cross sections and electromagnetic responses due to the coupling to the continuum. The properties of the unbound core $+\,n$ nuclei shape the structure of two-neutron halos, with the correlation between the valence neutrons playing a key role in binding the system [2].

In this contribution, we present some recent development for the theoretical description of nucleon-removal reactions populating unbound nuclei. First, we briefly recall the Transfer to the Continuum (TC) framework to study (p,pn) knockout reactions from two-neutron halo nuclei in inverse kinematics. Then, we consider the cases of ^{11}Li$(p,pn)^{10}$Li and ^{14}Be$(p,pn)^{13}$Be.

2. Transfer to the Continuum (TC)

The core $+\,n$ relative-energy spectra and momentum distributions in (p,pn) knockout reactions can be computed within the Transfer to the Continuum (TC) framework [3], which was recently extended to the case of three-body projectiles [4]. The process takes the form

$$\underbrace{(C+n_1+n_2)}_{A}+p \longrightarrow \underbrace{(C+n_2)}_{B}+n_1+p \tag{1}$$

This result contrasts with the findings in Ref. [12], where an s-wave resonance was proposed to explain the width of the momentum distribution in the energy region 0.4 - 0.5 MeV. This apparent inconsistency may arise from the different methods used to interpret the data. The analysis presented in Ref. [12] relays on a χ^2 procedure to assign the weight of s-, p- or d-components, while in our calculations the weights of the different components are fixed by the structure model and the reaction calculations. The limitations of the fitting procedure are already recognized in Ref. [12], in particular they acknowledge the "large statistical uncertainties that prevent a strict conclusion" due to the correlation of the fitting parameters. Furthermore, the analysis in Ref. [12] is based on the theoretical method by Hansen [15], which was devised for knockout reactions on heavier targets and yields momentum distributions for $\ell = 0, 1, 2$ with different widths than those obtined in our TC calcultations. It is our understanding that the present approach avoids many of the ambiguities in the previous work and reinforces the necessity for prior models of the three-body projectile in the analysis of this kind of experiments.

4. Conclusions

We have presented Transfer to the Continuum (TC) calculations to describe (p, pn) reactions induced by two-neutron halo nuclei, in which core + n unbound states are populated. Our method is based on a participant/spectator approximation of the transition amplitude, with all the structure information contained in the overlaps between the ground-state of the initial three-body nucleus and the continuum states of the two-body residual system. Within this framework, the usual ambiguities involved in the analysis of core+n relative-energy spectra using fitting procedures are avoided. Our results for ^{11}Li$(p, pn)^{10}$Li describe very well the available experimental data and confirm the parity inversion for $N = 7$ beyond the neutron dripline. For ^{14}Be$(p, pn)^{13}$Be, our analysis of the relative-energy spectrum and the corresponding momentum distributions is consistent with a dominance of p-waves at low excitation energies.

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Dineutron correlations in knockout reactions with Borromean halo nuclei

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Abstract. We study dineutron correlations in proton-target knockout reactions induced by Borromean two-neutron halo nuclei. Using a core + n + n three-body model for the projectile and a quasifree sudden reaction framework, we focus on the correlation angle as a function of the intrinsic neutron momentum. Our results indicate that the correlations are strong in a range of neutron momenta associated to the nuclear surface. We also discuss on the role of core excitations for such correlations.

1 Introduction

Borromean halo nuclei are loosely bound systems formed by a compact core and two valence neutrons, such that the core + n subsystem is unbound [1, 2]. The diffuse matter distribution arising from this particular arrangement has deep implications for their dynamics [3, 4] and provides information about the limits of nuclear stability [5]. A two-neutron halo wast first observed in the seminal work by Tanihata *et al.*, where a relatively large interaction cross section for ^{11}Li was reported [6]. Other cases have been studied over the years, including ^{6}He, ^{14}Be, ^{17,19}B, ^{22}C or ^{29}F [7–14]. The Borromean nature of these systems implies that the correlations between the valence neutrons are a key aspect to understand their properties [15]. These correlations tend to favour a compact neutron-neutron structure typically referred to as dineutron configuration [16], the extent of which is somewhat related to the amount of mixing between different-parity orbitals [17]. Coulomb dissociation and knockout reactions have been employed to access these spatial correlations, for instance in ^{11}Li, typically linked to a small angle between the neutrons in coordinate space and a large opening angle in momentum space [8, 18, 19]. Recently, a similar approach has been introduced via quasifree knockout of the halo neutrons with proton targets, (p, pn), which provides spectroscopic information of the projectile ground state while probing the unbound binary subsystems [10, 13, 20]. Interestingly, this enables the exploration of such correlations as a function of the neutron density by analyzing the average correlation angle as a function of the intrinsic neutron momentum [21, 22]. For ^{11}Li, it was reported that the dineutron correlations are localized at the surface of the nucleus [23], an idea already suggested in Ref. [16] and predicted by more recent theories [24, 25]

In this contribution we recall a quasifree sudden reaction framework to describe proton-target (p, pn) knockout reactions that incorporates the three-body structure of the Borromean core + n + n projectile and the unbound nature of the core + n residue in a consistent way. The method, which was succesfully applied to ^{11}Li, is now extended to ^{14}Be including core excitations. First, the theoretical approach is briefly discussed. Then, some results for the angular and intrinsic momentum distributions of ^{14}Be, as well as the correlation between them, are presented.

2 Theoretical description

As discussed in Refs. [21–23], intermediate-energy proton-target knockout reactions can be described within a quasifree sudden reaction framework. The model assumes a zero-range V_{pn} interaction, and absorption and distortion effects are included through an eikonal S-matrix between the projectile and the proton. In the case of a valence-neutron knockout from a Borromean halo nucleus, the transition amplitude takes the form

$$\mathcal{T} \propto \langle \phi_{\mathrm{c-n}}(\boldsymbol{k}_x, \boldsymbol{x}) \otimes e^{\boldsymbol{k}_y \cdot \boldsymbol{y}} | S(y) \Phi_{g.s.}(\boldsymbol{x}, \boldsymbol{y}) \rangle, \tag{1}$$

where $\{x, y\}$ are the usual Jacobi coordinates depicted in Fig. 1, and $\left\{k_x, k_y\right\}$ are the conjugated intrinsic momenta. Here $\Phi_{g.s.}(\boldsymbol{x}, \boldsymbol{y})$ represents the ground state of the Borromean core + n + n projectile, and $\phi_{\mathrm{c-n}}(\boldsymbol{k}_x, \boldsymbol{x})$ is a continuum state describing the unbound core + n subsystem after knockout, which accounts for final state interactions. If no absorption is included (i.e., $S = 1$) and final state interactions are ignored (i.e., replacing $\phi_{\mathrm{c-n}}(\boldsymbol{k}_x, \boldsymbol{x})$ by a plane wave in the x coordinate), the above amplitude $\mathcal{T}$ becomes a simple Fourier transform of the ground-state wavefunction $\Phi_{g.s.}(\boldsymbol{x}, \boldsymbol{y})$. Therefore, Eq. (1) can be understood as a distorted Fourier transform. More details about the derivation of this equation can be found in Ref. [22], where the method was then applied to ^{11}Li(p, pn). Continuum states $\phi_{\mathrm{c-n}}(\boldsymbol{k}_x, \boldsymbol{x})$ are calculated by solving the two-body problem with standard scattering boundary conditions. The three-body ground-state wave function $\Phi_{\mathrm{gs}}(\boldsymbol{x}, \boldsymbol{y})$ can be

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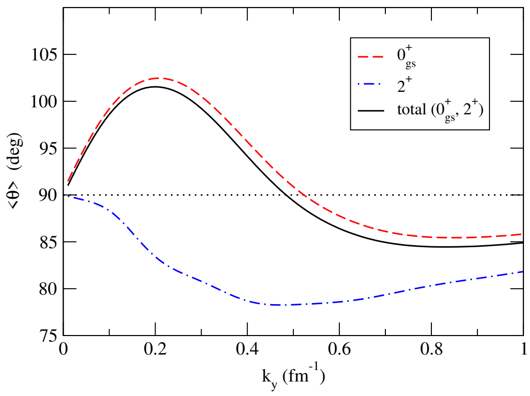

Figure 5. Average opening angle as a function of the intrinsic neutron momentum. The solid line is the complete calculation, while the dashed and dot-dashed lines correspond to the core left in its 0^+ ground state or first 2^+ excited state, respectively.

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Searching for universality of dineutron correlation at the surface of Borromean nuclei

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The dineutron correlation is systematically studied in three different Borromean nuclei near the neutron dripline, ^{11}Li, ^{14}Be and ^{17}B, via the (p, pn) knockout reaction measured at the RIBF facility in RIKEN. For the three nuclei, the correlation angle between the valence neutrons is found to be largest in the same range of intrinsic momenta, which can be associated to the nuclear surface. This result reinforces the prediction that the formation of the dineutron is universal in environments with low neutron density, such as the surface of neutron-rich Borromean nuclei.

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average correlation angle as a function of the intrinsic momentum of the removed neutron. This work follows the seminal work of Kubota et al. [14] who first proposed to use this observable to probe the location of dineutron correlation inside the nucleus, and extends the study to ^{14}Be and ^{17}B. A dineutron correlation appears in the periphery of ^{14}Be and ^{17}B as well, but is damped compared to ^{11}Li.

This study provides the first experimental hint of the universality of dineutron correlation in the low-density surface of Borromean nuclei. Even while fast nucleon removal induced by high-energy quasi-free scattering is the tool of choice to reduce the effect of final-state interactions, consistent measurements using different probes may help to confirm the universal character of our observation. The damping of dineutron correlation in ^{14}Be is interpreted as due to the presence of configurations with an excited core, that can be predicted within the three-body model. Higher statistics data incorporating gamma-ray coincidences, which enable core excitations to be probed, could be used to investigate this explanation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Binding-energy asymmetry in absorption explored through CDCC extended for complex potentials

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ABSTRACT

In this work, we present an extension of the Continuum-Discretized Coupled-Channel formalism to include the effects of absorption and excitation of the core through its interaction with the removed particle in the description of nuclear breakup reactions. This extension is performed via the inclusion of a complex energy-dependent interaction between core and removed particle and the use of a binormal basis to ensure orthogonality. The formalism is applied to neutron breakup reactions with a ^{12}C target at 70 MeV per nucleon for the loosely-bound ^{11}Be nucleus and the more deeply-bound ^{41}Ca nucleus, finding a moderate reduction in the cross section for the weakly-bound case and a strong reduction for the more deeply-bound case. Possible implications for the interpretation of intermediate-energy knockout reactions are discussed.

1. Introduction

Nucleon-removal reactions have a long and successful history in the study of the single-particle properties of nuclei [1–4]. In particular, nuclear breakup (or elastic breakup) reactions have been used extensively, specially in the study of loosely-bound and halo nuclei [5–9]. In these breakup reactions, a nucleon is removed from a nucleus a via interaction with a target A, leaving the target A in its ground state, as well as a residual core b and nucleon x ($a = b + x$), all of them detected in what is called the elastic breakup channel. The usual description for these reactions relies in a single-particle model of the nucleus, where the interaction between core b and removed nucleon x is assumed to be well described by an effective real interaction V_{bx} which reproduces the properties of the bound system a and in some cases the low-energy continuum of the $b-x$ system. The eigenstates of this potential are then taken as a good description of the continuum of the $b-x$ system and are used as the basis for Distorted Wave Born Approximation (DWBA) [10] or Continuum-Discretized Coupled-Channel (CDCC) [11] calculations to describe the reaction observables. However, in breakup reactions core b and nucleon x may end up in states with significant relative energies, where new channels beyond the single-particle excitation open, in particular the excitation and possible disintegration of b. The mere interaction between b and x can populate these open channels, thus reducing the cross section to the elastic breakup channel. These open channels cannot be considered in the description of breakup reactions described above but can nevertheless play a significant role, as has been shown for the breakup of ^{11}Be [12,13]. Generally the exclusion of these non-elastic channels restricts the description of breakup observables to low relative energies between the two fragments and to low binding energies of the removed nucleon, where their effect can be neglected. The exclusion of these open channels is particularly questionable when removing deeply-bound nucleons, where the large energy transfer enhances their population and subsequent decay of core nucleus b [14]. It is particularly in the removal of deeply-bound nucleons where a current open problem exists, in which theoretical predictions of nucleon-knockout cross sections severely overestimate experimental data [2,15], while for weakly-bound nucleons, the agreement is much better. We therefore find timely to explore the effects of non-elastic channels in breakup reactions, which will be included through the use of an effective complex energy-dependent interaction, in an approach similar to the widely-used optical model [10] and to the Ichimura-Austern-Vincent (IAV) description of non-elastic breakup [16]. It should be remarked that in Faddeev/AGS [17,18] calculations, the effects of complex potentials have been explored [19] but to our knowledge this study has not been extended to CDCC nor has it delved into the effects of non-orthogonality which naturally appear when considering complex potentials. The approach considered in this work

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Core-valence absorption in breakup and stripping reactions and its isospin dependence

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Abstract. In this work, the effect of nucleon-core absorption on nucleon removal reaction is explored through the use of complex nucleon-core interactions. Results are presented for exclusive breakup reactions, where absorption is explored through the use of a binormal basis in the continuum-discretized coupled-channel method, and for stripping nucleon knockout reactions, where absorption is considered through the application of an effective density in the eikonal approximation. Both methods show an increased effect of nucleon-core absorption when removing a deeply-bound nucleon, which leads to smaller cross sections, a reduction that is larger than in the weakly-bound case.

1 Introduction

Nucleon-removal reactions with medium-mass targets (^{9}Be, ^{12}C) have a long and successful history in the study of the single-particle properties of nuclei [1, 2]. In this kind of reactions, a projectile P is made to collide with a target T so that a nucleon N is removed from the projectile, and a residual core C is detected. If the nucleon N and the target T (in its ground state) are detected, $P(N+C)+T \rightarrow N+C+T$, the reaction corresponds to elastic (sometimes called diffractive) breakup, while the reaction process is called stripping if the nucleon is absorbed by the target and only the core is detected $P(N+C)+T \rightarrow C+X$. Elastic breakup is the main nucleon-removal process for the removal of halo and weakly-bound nucleons, while for more deeply-bound nucleons the importance of stripping increases with the binding energy of the removed nucleon, being the dominant contribution for removal from stable nuclei and for deeply-bound nucleons.

For the study of elastic breakup for weakly-bound nuclei, the state-of-the-art method is the Continuum-Discretized Coupled Channels method (CDCC) [3] while stripping reactions, which are usually measured at an energy of $\sim$ 100 MeV per nucleon, are usually analyzed using an eikonal sudden description [4]. Both methods, in their standard form, require a real interaction between the nucleon and the core in the final state, in order to ensure the properties of orthogonality and closure for the nucleon-core eigenstates. However, the final-state-interaction between removed nucleon and core can lead to excitation and breakup of the latter, leading to a loss of flux (and therefore cross section) that is usually described by an imaginary part in the interaction, so an extension in these methods to consider complex interactions is required to describe this processes.

In this work we describe briefly two such extensions for the CDCC and eikonal methods and present results for cross sections corresponding to the removal of weakly- and deeply-bound nucleons.

2 Elastic breakup

2.1 Theoretical framework: CDCC

In the CDCC method, the full three-body wavefunction for the $C+N+T$ system $\Psi^{(+)}$ is expanded in eigenstates of the $C+N$ Hamiltonian ϕ_j, with a discretization procedure (usually a binning procedure) to express the infinite continuum eigenstates in a finite discrete basis [3].

$$\Psi(\mathbf{R},\mathbf{r}) = \sum_j \chi_j(\mathbf{R})\phi_j(\mathbf{r}), \tag{1}$$

where $\mathbf{R}$ is the relative coordinate between projectile and target, $\mathbf{r}$ is the one between nucleon and core and $\chi_j(\mathbf{R})$ is the coefficient of state $\phi_j(\mathbf{r})$ in $\Psi(\mathbf{R},\mathbf{r})$. Provided the eigenstates ϕ_j are orthogonal, one can obtain from the Schrödinger equation a set of coupled equations for $\chi_j(\mathbf{R})$,

$$\begin{aligned}&\sum_j \left((T_R - E_i)\left\langle\phi_i|\phi_j\right\rangle + \left\langle\phi_i|U_{CT}+U_{NT}|\phi_j\right\rangle\right)\chi_j(\mathbf{R}) = \\ &\sum_j \left((T_R - E_i)\delta_{ij} + U_{ij}\right)\chi_j(\mathbf{R}) = 0,\end{aligned} \tag{2}$$

where $U_{ij} = \left\langle\phi_i|U_{CT}+U_{NT}|\phi_j\right\rangle$ is the coupling potential and U_{CT}, U_{NT} are the core-target and nucleon-target

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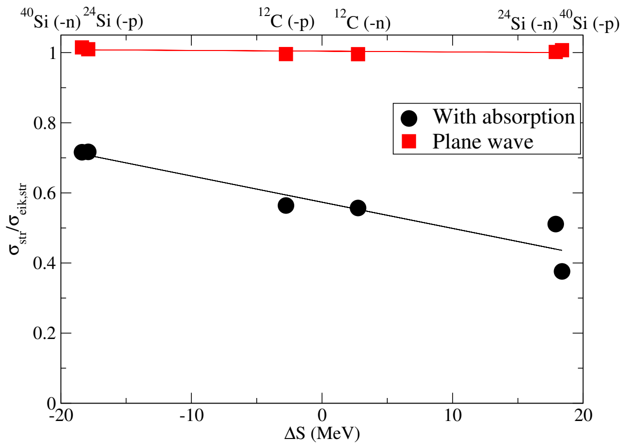

Figure 4. Ratio between computed cross sections and standard eikonal calculations as a function of the difference in binding energies $\Delta S = S_{n(p)} - S_{p(n)}$. Red squares correspond to an effective density with no potential and black circles to one with the Morillon imaginary potential(See text). Linear fits of the trends of the calculations with and without absorption are shown.

in the weakly-bound cases, which results in unphysical $R_s > 1$ values for the "quenching factors" for weakly-bound-nucleon removal. The reason for this overestimation could be related to the fact that the potential by Morillon (as is usual for global potentials) presents a finite imaginary part even for weakly-bound nucleons at low energies, where the lack of open channels should lead to no absorption. This imaginary part is meant to describe compound-nucleus processes which are not well described in optical model calculations but that ultimately lead to the original elastic channel and thus do not result in absorption and therefore should not be considered in the present calculations. Methods to estimate these contributions to remove them from the calculations would help reduce this problem at low binding energies and are currently in consideration [13].

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THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Theoretical Physics

The Hussein–McVoy formula for inclusive breakup revisited

A Tribute to Mahir Hussein

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Abstract In 1985, Hussein and McVoy [Nuc. Phys. A445 (1985) 124] elucidated a formula for the evaluation of the nonelastic breakup ("stripping") contribution in inclusive breakup reactions. The formula, based on the spectator core model, acquires a particularly simple and appealing form in the eikonal limit, to the extent that it has become the standard procedure to analyze single-nucleon knockout reactions at intermediate energies. In this contribution, a critical assessment of this formula is presented and its connection with other, noneikonal expressions discussed. Some calculations comparing the different formulae are also presented for the one-nucleon removal of ^{14}O+^{9}Be reaction at several incident energies.

1 Introduction

Breakup reactions have been extensively used to extract nuclear structure information (binding energies, spectroscopic factors, electric response to the continuum, etc) and have also permitted to improve our understanding of the dynamics of reactions among composite systems. When the projectile dissociates into two fragments, the process can be described as an effective three-body problem, which can be schematically represented as $a + A \to b + x + A$, where a represents the projectile which eventually dissociates into $b + x$. Even in this simplified three-body picture, the theoretical description of the process is not straightforward due to the presence of three particles in the final state.

In some applications, one is interested in the inclusive process in which only one of the fragments (say, b) is measured experimentally, that we represent schematically as $A(a, b)X$. These inclusive cross sections are needed, for example, in the application of the surrogate method [1] and in spectroscopic studies by means of intermediate-energy knockout reactions [2–4].

The evaluation of inclusive breakup reactions poses a challenging theoretical problem because many processes can in principle contribute to the b singles cross section. When the two fragments b and x "survive" and the target remains in its ground state, the process is referred to as *elastic breakup* (denoted EBU hereafter), also called *diffraction dissociation*.

The remaining part of the inclusive breakup cross section, that we denote globally as *nonelastic breakup* (NEB), includes those processes in which the x particle interacts nonelastically with the target nucleus. This involves, for example, the transfer of x to a bound state of the residual system $B = A + x$, the fusion of x forming a compound nucleus (incomplete fusion) or simply the target excitation by x. If x is a composite system, it also includes any process in which the latter is broken or excited in any way. The explicit evaluation of all these processes is not possible in general so several authors proposed closed-form formulae which avoid the sum over the final states. Interestingly, all these formulae display a common structure, given by

$$\left.\frac{d^2\sigma}{dE_b d\Omega_b}\right|_{\mathrm{NEB}} = -\frac{2}{\hbar v_a}\rho_b(E_b)\langle\varphi_x|W_x|\varphi_x\rangle, \tag{1}$$

where $\rho_b(E_b) = k_b\mu_b/[(2\pi)^3\hbar^2]$ is the density of states (with μ_b the reduced mass of $b + B$ and k_b their relative wave number), W_x is the imaginary part of the optical potential U_x, which describes $x + A$ elastic scattering. Expression (1) offers a intuitively appealing interpretation of nonelastic

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cent (IAV) model, recently revisited and applied by several groups, as well as from the three-body formula of Austern et al. [11]. We have also shown that, owing to the particular choice of the auxiliary interaction U_{aA}, the eikonal version of the HM formula (EHM) incorporates genuine three-body effects. These effects are also present in the more general three-body formula of Austern et al., but in a more complicated way.

Preliminary calculations for the one-nucleon removal in the ^{14}O+^{9}Be reaction show that the EHM formula reproduces accurately the results of the IAV model. For the removal of the strongly bound neutron ($S_n = 23.2$ MeV), the noneikonal HM formula is also in good agreement with the IAV result. However, for the one-proton removal ($S_p = 4.6$ MeV), the noneikonal HM formula tends to overestimate the IAV result. It will be interesting to extend these calculations to other systems and energies to see whether these conclusions remain.

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Data Availability Statement This manuscript has no associated data or the data will not be deposited. [Authors' comment: The results shown are purely theoretical. We do not compare with any experimental data.]

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Opening angle and dineutron correlations in knockout reactions with Borromean two-neutron halo nuclei

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Background: Knockout reactions with proton targets provide an invaluable tool to access the properties of two-neutron halo nuclei. Recently, experimental results for the average opening angle as a function of the intrinsic neutron momentum in ^{11}Li have shown a localization of dineutron correlations on the nucleus surface.

Purpose: Study the model dependence and the effect of distortion and absorption on the opening angle distributions to assess the reliability of this observable to extract properties of Borromean two-neutron halo nuclei.

Method: A quasifree sudden model is used to describe the knockout process, where absorption effects are modeled by the eikonal S matrix between the proton target and the core of the Borromean nucleus. Final states in momentum space are built within a three-body model for the projectile, which enables the description of momenta and opening angle distributions.

Results: A strong dependence on absorption effects is found for the opening angle at large intrinsic momenta, while the region of lower momenta is mostly insensitive to them. Reasonable agreement with the available data is obtained for ^{11}Li at low momenta with weights for s and p waves different from those previously reported, showing a model dependence in their extraction. For ^{19}B, test calculations show marked sensitivity to small p-wave components.

Conclusions: The opening angle for (p, pn) knockout reactions on Borromean nuclei at small intrinsic momenta is a reliable observable mostly sensitive to the structure of the Borromean nucleus. For larger momenta, the reaction mechanism leads to a larger distortion of the distribution. In the case of nuclei with small components of opposite parity to the dominant ones, this observable can be used to explore them. The relation between dineutron in coordinate space and opening angle in momentum space is found to be model dependent.

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I. INTRODUCTION

Two-neutron halo nuclei along the neutron dripline are at the focus of our efforts to understand the limits of nuclear stability. Since the first observation of an abnormally large interaction cross section for ^{11}Li [1], the topic has driven enormous experimental and theoretical endeavors [2]. The term *halo* refers to a diffuse matter distribution corresponding to the valence neutrons, which are loosely bound and explore distances far from the more compact core [3,4]. The structure of core + n + n two-neutron halo nuclei is usually called Borromean [5,6], where the binary subsystems core + n and n + n are unbound. It is then clear that the correlations between the valence neutrons are essential in binding the system [5,7,8]. These correlations favor a strongly localized two-neutron structure, also referred to as dineutron configurations, which is enhanced by a large mixing between different-parity orbitals [9]. In ^{11}Li, for instance, three-body calculations show that the halo wave function is very much determined by the mixing between s- and p-wave states in the low-lying spectrum of the unbound ^{10}Li system [8,10,11], and a dominant dineutron peak is obtained in the corresponding two-neutron density. A similar situation has been recently explored for the heavier two-neutron halo ^{29}F, where the mixing between intruder $p_{3/2}$ components with standard-order $d_{3/2}$ enhances the dineutron configuration and the size of the halo [12,13]. In the case of two-neutron halo nuclei without a strong mixing between different-parity components, such as ^{6}He or ^{19}B, the dineutron is less pronounced [5,14,15].

Different techniques have been employed to investigate the correlations between the halo neutrons experimentally. The angle between the two valence neutrons in ^{11}Li was estimated from a Coulomb breakup measurement, using the link between the extracted $E1$ strength into the continuum and the so-called cluster sum rule in a core + n + n model, and assuming an inert core [16]. The average angle obtained was $\langle\theta_{nn}\rangle = 48^{+14}_{-18}$ deg, well below the value of 90 deg expected for a no-correlation scenario [17,18]. This estimation was refined in a subsequent theoretical work, pointing toward a larger $\langle\theta_{nn}\rangle$ value, but always compatible with a correlated pair in coordinate space [19]. It is worth noting, however, that the simple relation between the cluster sum rule for dipole transitions and the geometrical configuration of the two-neutron halo is model dependent, and effects such as core

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Eikonal calculation of $(p, 3p)$ cross sections for neutron-rich nuclei

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In this work, I present the first, to my knowledge, theoretical description of two-proton removal reactions with proton target $(p, 3p)$ for medium-mass nuclei at intermediate energies and present cross sections for the different bound states of the residual nucleus with two fewer protons. The description of the reaction assumes two sequential "quasifree" collisions between the target and removed protons and considers eikonal propagation in between. The formalism is applied to the reactions ^{12}C$(p, 3p)$ ^{10}Be, ^{28}Mg$(p, 3p)$ ^{26}Ne, and ^{54}Ca$(p, 3p)$ ^{52}Ar, finding reasonable agreement to experimental data for the ^{12}C target and an overestimation of a factor ≈3 for the more neutron-rich and ^{54}Ca, which is similar to the results found in two-proton knockout experiments with ^{9}Be and ^{12}C targets.

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I. INTRODUCTION

Two-proton knockout reactions from neutron-rich nuclei using ^{9}Be and ^{12}C at intermediate energies have been shown to proceed as a direct reaction [1] and were shown to be able to populate very exotic nuclei via the removal of two protons from already proton-deficient nuclei [1,2]. Equivalently, two-neutron knockout reactions from proton-rich nuclei have been used to study very neutron-rich nuclei [3]. The analysis of these reactions using an eikonal sudden description [4,5] has yielded significant results on the structure of these nuclei [6–10] and on the effect of nuclear correlations on the observables of the reactions, and therefore their value as a probe of these correlations [3,5,11–13]. The development of new hydrogen-target detectors, such as active targets [14], or MINOS [15], where a thick liquid-hydrogen target is coupled to a vertex tracker for the recoil protons, has opened the use of proton-induced reactions as reliable probes to explore exotic nuclei, where the reaction mechanism can be explored and understood thanks to the tracking of the paths of the outgoing particles. Therefore, two-proton removal reactions with proton targets, or $(p, 3p)$, appear as an appealing probe to produce exotic nuclei by removing two protons from already proton-deficient species, and to be able to study their properties thanks to the simpler reaction mechanism and the possibility for proton tracking. Unfortunately, as was the case for one-neutron removal, the reaction models used with heavier targets [16] are not applicable for the case of the proton target, due to the significant recoil of the target proton. Models considering a "quasifree" interaction between removed and target protons have been more successful in the description of the experimental data for reactions with proton targets $(p, 2p)$ [17–20], so a similar approach for $(p, 3p)$ reactions seems promising and is required in order to fully exploit $(p, 3p)$ reactions as a spectroscopic tool using the experimental possibility that hydrogen active targets provide. This need has been indicated in previous publications [21] where the lack of such a theory has hindered the analysis of the experimental data.

This work aims to provide a theoretical formalism for $(p, 3p)$ reactions, based on the assumption of "quasifree" collision between the target and removed protons, and is structured as follows. Section II presents the theoretical formalism and briefly shows its derivation, Sec. III presents calculations of $(p, 3p)$ reactions for the stable ^{12}C target as validation of the theory and results for the neutron-rich targets ^{28}Mg and ^{54}Ca. Finally, Sec. IV presents the conclusions and summary of this work as well as future extensions.

II. THEORETICAL FRAMEWORK

A process $p + (A + 2) \rightarrow 3p + A$ is considered, where a projectile proton collides with the target nucleus $A + 2$ removing two protons from it, with the remaining nucleus A remaining bound. For the derivation, an infinite mass for A will be assumed. Following the results from [22], the process is described as two sequential and independent collisions between the projectile proton and two protons of the target, with the residual nucleus A remaining as an inert spectator. It will also be assumed that the reaction occurs fast enough for the internal degrees of freedom of A to remain frozen during the collision, so that the removal of the two protons does not alter the state of A. For ease of description, in this derivation, the protons will be treated as distinguishable, since, following Goldberger and Watson [23], it is sufficient to consider their antisymmetrization in the proton-proton interaction V_{pp}. As such, p_0 corresponds to the incoming proton, with momentum $\hbar\mathbf{k}_0$. p_0 is then assumed to collide with the first proton p_1, which is expelled with an asymptotic momentum $\hbar\mathbf{k}_1$. Then p_0 collides with a second proton p_2, and both escape the

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THE EUROPEAN PHYSICAL JOURNAL A

Special Article - New Tools and Techniques

PUMA, antiProton unstable matter annihilation

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Abstract PUMA, antiProton Unstable Matter Annihilation, is a nuclear-physics experiment at CERN aiming at probing the surface properties of stable and rare isotopes by use of low-energy antiprotons. Low-energy antiprotons offer a very unique sensitivity to the neutron and proton densities at the annihilation site, i.e. in the tail of the nuclear density. Today, no facility provides a collider of low-energy radioactive ions and low-energy antiprotons: while not being a collider experiment, PUMA aims at transporting one billion antiprotons from ELENA, the Extra-Low-ENergy Antiproton ring, to ISOLDE, the rare-isotope beam facility of CERN. PUMA will enable the capture of low-energy antiprotons by short-lived nuclei and the measurement of the emitted radiations. In this way, PUMA will give access to the so-far largely unexplored isospin composition of the nuclear-radial-density tail of radioactive nuclei. The motivations, concept and current status of the PUMA experiment are presented.

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Letter

Isospin dependence in single-nucleon removal cross sections explained through valence-core destruction effects

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ABSTRACT

The discrepancy between experimental data and theoretical calculations in one-nucleon removal reactions at intermediate energies (quantified by the so-called "quenching factors") and its dependence on the isospin asymmetry of the nuclei has been an open problem in nuclear physics for the last fifteen years. In this work, we propose an explanation for this long-standing problem, which relies on the inclusion of the process of core destruction due to its interaction with the removed nucleon. To include this effect, we extend the commonly used eikonal formalism via an effective nucleon density, and apply it to a series of nucleon knockout reactions. The effect of core destruction is found to depend strongly on the binding energy of the removed nucleon, leading to a significant reduction of the cross section for deeply bound nucleons, which reduces the isospin dependence of the "quenching factors", making them more consistent with the trends found in transfer and (p, pN) reactions.

1. Introduction

Single nucleon knockout reactions with light targets (^{9}Be, ^{12}C) at intermediate energies have been a key experimental tool to study the structure of unstable nuclei [1–7]. These reactions can be described as $P(C+V)+T \rightarrow C+X$, where the projectile P collides with the target T so that the residual nucleus (the core) C is detected, while the valence nucleon V can be detected (diffractive breakup) or is absorbed (stripping). From the momentum distribution of the core, properties of the valence nucleon can be extracted [8,9]. The dynamics of the collision is standardly modelled within the eikonal approximation [10], which is reasonable for sufficiently high energies (∼80-90 MeV per nucleon). Other nucleon removal reactions such as nucleon transfer [11] and quasifree nucleon removal with proton targets (p, pN) [12] provide complementary information on the properties of the removed nucleons.

A systematic study of the cross section of nucleon knockout reactions in light and medium-mass nuclei showed an intriguing trend [13], where the discrepancy between experimental cross sections and theoretical predictions, quantified by the so-called "quenching factor" ($R_s = \sigma_{\rm exp}/\sigma_{\rm theor}$), shows a marked dependence on the isospin asymmetry of the nucleus, such that for very asymmetric nuclei, the removal of the more abundant nucleons presents a small "quenching" ($R_s \sim 1$) while the removal of the less abundant ones suffers from a large reduction ($R_s \sim 0.2 - 0.4$). This tendency has been interpreted as the effect of short-range correlations, 3N-force effects or explicit couplings of near- threshold single-particle configurations to the continuum on the less abundant and more deeply bound nucleons, which go beyond the standard shell-model description for the more deeply-bound nucleons. However, other systematic studies with transfer [11,14,15] and $(p, 2p)$ reactions [16–18] have failed to find this marked dependence on isospin asymmetry, while the addition of new data for heavy-target nucleon-knockout reactions has only reinforced it [19,20]. A recent overview on this topic can be found in [21]. Whether this isospin dependence is a manifestation of nuclear structure effects beyond standard, small-scale shell-model calculations or an artefact derived from a not yet understood deficiency of the reaction model [22] is a pressing question in nowadays nuclear physics which calls for a careful revision of both the structure and reaction inputs employed in these analyses.

Eikonal descriptions assume straight-line trajectories for core and valence nucleon and ignore their mutual final-state interaction. A potentially important effect absent from this description of knockout reactions is the destruction of the residual core because of its interaction

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Review

Quenching of single-particle strength from direct reactions with stable and rare-isotope beams

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ABSTRACT

In this review article we discuss the present status of direct nuclear reactions and the nuclear structure aspects one can study with them. We discuss the spectroscopic information we can assess in experiments involving transfer reactions, heavy-ion-induced knockout reactions and quasifree scattering with $(p, 2p)$, (p, pn), and $(e, e'p)$ reactions. In particular, we focus on the proton-to-neutron asymmetry of the quenching of the spectroscopic strength.

Contents

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Multiple Mechanisms in Proton-Induced Nucleon Removal at ∼100 MeV/Nucleon

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We report on the first proton-induced single proton- and neutron-removal reactions from the neutron-deficient ^{14}O nucleus with large Fermi-surface asymmetry $S_n - S_p = 18.6$ MeV at ∼100 MeV/nucleon, a widely used energy regime for rare-isotope studies. The measured inclusive cross sections and parallel momentum distributions of the ^{13}N and ^{13}O residues are compared to the state-of-the-art reaction models, with nuclear structure inputs from many-body shell-model calculations. Our results provide the first quantitative contributions of multiple reaction mechanisms including the quasifree knockout, inelastic scattering, and nucleon transfer processes. It is shown that the inelastic scattering and nucleon transfer, usually neglected at such energy regime, contribute about 50% and 30% to the loosely bound proton and deeply bound neutron removal, respectively. These multiple reaction mechanisms should be considered in analyses of inclusive one-nucleon removal cross sections measured at intermediate energies for quantitative investigation of single-particle strengths and correlations in atomic nuclei.

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Time scales in nuclear structure and nuclear reactions of exotic nuclei

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Summary. — Two relevant time scales are introduced to describe the interplay of nuclear structure and nuclear reactions for exotic nuclei. The collision time represents the time dependence of the external field created by the target on the projectile. The excitation time represents the characteristic time dependence of the projectile degrees of freedom due to its internal Hamiltonian. The comparison of these two time scales indicate when approximate treatments of the reaction, such as the sudden approximation, implicit in the eikonal treatment, is applicable. An approach based on these time scales is used to describe recent experimental data as well as theoretical calculation involving Coulomb break-up, stripping reactions and (p, pN) reactions. It is suggested that the dependence of the stripping cross sections on the difference of binding energies of protons and neutrons may be associated to inadequacy of the eikonal approximation to describe the removal of strongly bound nucleons at intermediate energies.

1. – Introduction

Nuclear reactions can be understood as a procedure to place a nucleus to be studied (i.e. the projectile) in a time dependent external field created by other one (the target). This field is a combination of the long-range Coulomb interaction (dominant for a heavy target) and the short-range nuclear interaction (dominant for a light target). As a result of this interaction, the projectile can be excited, leading, in the case of exotic, weakly-bound nuclei, to the population of break-up states. The process of excitation depends on the magnitude of the external field as well as on its time structure. Typically, the external field is maximum at the instant of time when both nuclei are at the distance of

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5. – Conclusions

The collision time and the excitation time are relevant time scales for a nuclear reaction. When the collision time is short compared to the excitation time, approximate treatments of the collision dynamics such the sudden approximation implicit in the eikonal approximation are justified. When the collision time is comparable or longer than the collision time, and the effect of the external field is small, first order semiclassical perturbative treatments, such as the equivalent photon method are applicable. When these conditions are not applied, as it is the case for ^{11}Be break-up on heavy targets around the barrier, a full quantum mechanical treatment is required. For ^{11}Be scattering, it is found that both halo and core degrees of freedom are relevant, and the consistent description of elastic, inelastic and break up cross sections require a continuum discretized coupled channels calculation which involves target excitation.

The dependence of the ratio of stripping cross section to theoretical values with the difference of binding energies of protons and neutrons can be related to the fact that the excitation time for strongly bound nucleons is comparable to the collision time. This may indicate that one needs to go beyond the eikonal approximation to describe stripping at intermediate energies.

The (p, pN) reactions at relativistic energies present a collision time that is very short compared with the excitation times, both of weakly and strongly bound nucleons. This is consistent with the fact that the ratio of experimental cross sections to different theoretical calculations do not present a dependence on the separation energy of protons and neutrons.

* * *

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Regular Article - Experimental Physics

Breakup reactions and their ambiguities

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Abstract We review the ambiguities in the nuclear information extracted from breakup reactions, focusing on those originating from the description of the reaction mechanism and the overall ambiguity inherent to their interpretation in terms of shell occupancies. We present the current discussion about nucleon knockout reactions and how the understanding of the reaction mechanism would help reducing uncertainties. For the former, we consider the case of ^{11}Li, due to the existing large data set. For the latter, we recall the paradigmatic example of the electro-dissociation of the deuteron to address the question of the scale and scheme dependence from the theoretical framework used for the interpretation.

1 Introduction

Few years after the discovery and first studies of halo nuclei [1–5], Bertulani and Hussein investigated the dissociation of neutron-rich nuclei from secondary beams impinging on various targets [6]. They concluded, at that time, that *the interpretation of almost all recent experimental studies with secondary radioactive beams is ambiguous*. We take this statement as a starting point to address the following question thirty years later: how ambiguous is the interpretation of breakup (dissociation) reactions?

To investigate the sources of ambiguity, we review the most recent experimental work and conclusions about the structure of ^{11}Li to quantify how much various interpretations differ on the same nuclear system as discussed in Ref. [6]. We also overview the sources of ambiguities in the nuclear-breakup-reaction mechanism as they are discussed today. To illustrate the model-dependencies of orbital occupancies, we remind the historical case of the D-state probability of the deuteron and the "simplest" breakup reaction: the electro-disintegration of the deuteron.

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2 General description of break-up reactions

In order to present the sources of ambiguity let us introduce a schematic expression for the T-matrix corresponding to the removal of a nucleon N from the projectile P leaving a core C $(P = N + C)$ via the interaction with a structureless target T, for simplicity:

$$T = \left\langle \Psi(\mathbf{R}, \mathbf{r}, \xi) | V_{NT} + V_{CT} | e^{iKR} \Phi_P(\mathbf{r}, \xi) \right\rangle, \quad (1)$$

where $\mathbf{R}$ is the coordinate between projectile and target and $\mathbf{K}$ their asymptotic initial relative momentum, $\mathbf{r}$ is the coordinate between nucleon and core and ξ corresponds to all internal coordinates of the core. Φ_P is the wave function of the projectile and Ψ is the exact final wavefunction. Usual assumptions taken in the analysis of nucleon removal reactions are to neglect exchange processes, where the emitted nucleon is not the one that interacts with the target, and to prevent the core's internal degrees of freedom from being excited during the reaction, which results in an effective $V_{CT}(\mathbf{R}, \mathbf{r})$ core target interaction that does not depend on the internal degrees of freedom of the core. This results in the wave function for the final channel $\Psi(\mathbf{R}, \mathbf{r}, \xi)$ being factorizable $\Psi(\mathbf{R}, \mathbf{r}, \xi) = \psi(\mathbf{R}, \mathbf{r})\Phi_C(\xi)$ in a 3-body wave function $\psi(\mathbf{R}, \mathbf{r})$ and the wave function of the residual core $\Phi_C(\xi)$:

$$T \simeq \int \mathrm{d}\mathbf{R}\mathrm{d}\mathbf{r}\mathrm{d}\xi\, \psi^*(\mathbf{R}, \mathbf{r})\Phi_C^*(\xi)(V_{NT} + V_{CT}) e^{iKR} \Phi_P(\mathbf{r}, \xi). \quad (2)$$

We note that the integral over ξ only involves $\Phi_P(\mathbf{r}, \xi)$ and $\Phi_C(\xi)$:

$$\int \mathrm{d}\xi\, \Phi_C^*(\xi)\Phi_P(\mathbf{r}, \xi) = \psi_{NC}(\mathbf{r}). \quad (3)$$

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Elastic, inelastic, and one-neutron transfer angular distributions of ^{6}Li + ^{120}Sn at energies near the Coulomb barrier

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The elastic scattering, first 2^+ and 3^- target inelastic excitation and one neutron pickup angular distributions for the ^{6}Li + ^{120}Sn reaction have been measured for three bombarding energies (19, 24, and 27 MeV). Data have been analyzed through coupled-channel calculations and continuum-discretized coupled-channel calculations extended to include target excitation. In general, both theoretical models give a reasonable description of the data. For the elastic and inelastic angular distributions taken at $E_{\rm lab} = 24$ and 27 MeV, the continuum-discretized coupled-channel results are slightly better in comparison to the coupled-channel predictions. For the elastic and inelastic angular distributions measured at $E_{\rm lab} = 19$ MeV, the effect of the break-up channel seems to be quite important. At this energy, the elastic scattering data can be well explained by coupled channel calculations in which a strong absorptive optical imaginary potential is considered. In particular, the continuum-discretized coupled-channel theoretical results provided the best description of the 3^- excitation data at 19 MeV.

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I. INTRODUCTION

The nuclei of our present universe have been generated from a series of reactions that took place in different environments, from the interior of stars to supernovae. The series of long chains of reactions that generated all of these nuclei initiated with hydrogen, helium, and lithium isotopes created in the primordial nucleosynthesis [1]. The correct determination of the abundance of these initial nuclei is still of paramount importance for astrophysics and its correlated fields, since they consist in a probe to cosmological models and their parameters [2]. Although the experimental abundances of deuterium and ^{3}He are consistent with theoretical models [3], there is a great disagreement between experimental observations and theory for ^{6}Li and ^{7}Li isotopes [4]. For ^{7}Li, this fact is known as *the lithium problem* [5], and some authors claim the existence of a *second lithium problem* related to ^{6}Li [6].

The ^{6,7}Li primitive abundances are based on the observation of low metallicity stars (given by the presence of elements heavier than helium) located in the halo of our galaxy. In these stars, the lithium abundance displays the so-called Spite plateau [7,8], indicating that their abundance is independent of the metallicity of the star. The Spite plateau indicates that the deposited lithium was originated on the primordial nucleosynthesis and was not depleted from the surface of such stars. Even thought the ^{6}Li isotope has been poorly generated in the primordial nucleosynthesis, its importance is enormous, since ^{6}Li participates on several reactions that have contributed to the synthesis of the elements present in our universe. For instance, the $\alpha(^{2}\mathrm{H}, \gamma)\,^{6}$Li and $^{6}\mathrm{Li}(p, \alpha)\,^{3}$He reactions [9], that respectively create and annihilate the ^{6}Li isotope, can have a great impact in the deuterium and ^{3,4}He abundances, which in turn played a central role in the primordial nucleosynthesis scenario.

The calculations of the initial abundance of the elements in our earlier universe depends on the nuclear cross sections of the reactions which occurred there. If one wants to properly describe such reactions and their network, it is of ultimate importance to understand all the mechanisms that a given nucleus may undergo. In this sense, reactions involving lithium isotopes can be challenging, since they can undergo the break-up (BU) process. Both lithium isotopes may be described by an α core, associated with a valence particle (^{2}H in the case of ^{6}Li and ^{3}H for the ^{7}Li), that is weakly bound to the α (1.47 MeV for ^{6}Li and 2.47 MeV for ^{7}Li). The possibility of the projectile to break-up during its interaction with other nuclei gives rise to several new paths for the nuclear reaction mechanism to occur. For instance, in the fusion process exists the possibility that all fragments are captured by the target (complete fusion), or just one of them to be fused with it (incomplete fusion). The role played by the BU process in the fusion remains a topic of great interest in the field of nuclear physics [10–12]. The BU may also have an impact on other several reaction channels, such as elastic [13,14], neutron transfer [15], and charged particle transfer [16].

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Transfer to the continuum calculations of quasifree (p,pn) and (p,2p) reactions

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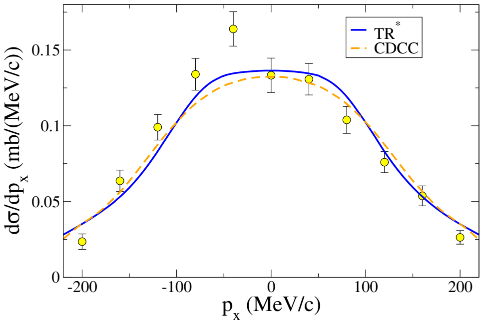
Abstract

Nucleon removal (p, pn) and $(p, 2p)$ reactions at intermediate energies have gained renewed attention in recent years as a tool to extract information from exotic nuclei. The information obtained from these experiments is expected to be sensitive to deeper portions of the wave function of the removed nucleon than knockout reactions with heavier targets. In this contribution, we present calculations for $(p, 2p)$ and (p, pn) reactions performed within the so-called *transfer to the continuum* method (TR*). Results for stable and unstable nuclei are presented, and compared with experimental data, when available.

1 Introduction

Quasi-free nucleon removal reactions with proton projectiles, or (p, pN) reactions, have been extensively used to obtain information on the single-particle observables of nuclei. In these reactions, a proton beam of high-energy (> 100 MeV) collides with a nucleus with A nucleons, and events are selected in which one nucleon is extracted and a residual nucleus of $A - 1$ nucleons is detected, in either its ground or an excited state. In this regime of energies, the proton has a maximum mean free path in the nucleus so it can be assumed to interact only with the extracted nucleon, hence the name "quasi-free".

Thanks to the new facilities which produce beams with unstable nuclei, (p, pN) reactions have been extended to study unstable nuclei, employing re-



	TR*	CDCC	Theor.
S_F	2.11	2.13	2.80

Figure 2: Transversal momentum distribution for ^{18}C$(p, pn)^{17}$C* at 81 MeV/A. TR* and CDCC calculations are presented. (CDCC and experimental data are extracted from [5]). Spectroscopic factors (S_F) are presented for both calculations.

(S_F), obtained with a shell-model calculation with the WBP interaction [7]. We find a very good agreement between both calculations and the experimental data, which validates the use of TR* in this regime of energies.

4 Conclusions

Preliminary calculations indicate that the TR* provides a suitable framework to study (p, pN) reactions at energies of ~ 100 MeV/A. We expect the method to be adequate at higher energies, of around hundreds of MeV/A, where the CDCC method becomes unfeasible.

References

[1] A. M. Moro and F. Nunes, *Nucl. Phys. A*, **767** (2006) 138; A. M. Moro, *To be published in Phys. Rev. C*

[2] A. Deltuva et al., *Phys. Rev. C*, **76** (2007) 064602

[3] V. G. J. Stoks et al., *Phys. Rev. C*, **49** (1994) 2950

[4] L. Rikus et al.: *Nucl. Phys. A*, **414** (1984) 413

[5] Y. Kondo et al.: *Phys. Rev. C*, **79** (2009) 014602

[6] J. P. Jeukenne et al., *Phys. Rev. C*, **16** (1977) 80

[7] E. K. Warburton and B. A. Brown: *Phys. Rev. C*, **46** (1992) 923

Transfer to the Continuum Calculations of Quasifree (p, pn) and $(p, 2p)$ Reactions at Intermediate and High Energies

M. Gómez-Ramos and A.M. Moro

Abstract Nucleon removal (p, pN) reactions at intermediate energies have gained renewed attention in recent years as a tool to extract information from exotic nuclei performing reactions in inverse kinematics with exotic beams incident on proton targets. In this contribution, we present calculations for (p, pN) reactions performed within the so-called *transfer to the continuum* method (TR*), a fully quantum mechanical formalism, focusing on the momentum distributions of the emitted core.

Nucleon removal (p, pN) reactions are reactions in which a high-energy proton beam collides with a target of A nucleons, in such a way that a nucleon is extracted from the target leaving a residual nucleus C with $A - 1$ nucleons, in its ground state or an excited state.

Recently (p, pN) reactions have received a renewed interest due to their extension to the study of unstable nuclei, employing inverse kinematics with radioactive beams impinging on proton targets. Measurements of these reactions are currently under way.

In this contribution we have studied some (p, pN) reactions, employing the *transfer to the continuum* formalism [1]. This formalism is based on the evaluation of the prior form transition amplitude for the process: $p + A \to p + N + C$:

$$\mathscr{T}^{3b}_{p+A\to p+N+C} = \left\langle \Psi^{3b(-)}_{p+N+C} | V_{pN} + U_{pC} - U_{pA} | \psi_{N+C}\chi^{(+)}_{p+A} \right\rangle, \tag{1}$$

where U_{pC} and U_{pA} are the optical potentials for $p + C$ and $p + A$, V_{pN} an effective nucleon-nucleon interaction, ψ_{N+C} the initial state of the $N + C$ nucleus and $\Psi^{3b(-)}_{p+N+C}$ the exact 3-body wavefunction. In the TR* formalism, $\Psi^{3b(-)}_{p+N+C}$ is expanded

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A.M. Moro
e-mail: moro@us.es

J.-E. García-Ramos et al. (eds.), *Basic Concepts in Nuclear Physics: Theory, Experiments and Applications*, Springer Proceedings in Physics 182,
DOI 10.1007/978-3-319-21191-6_6

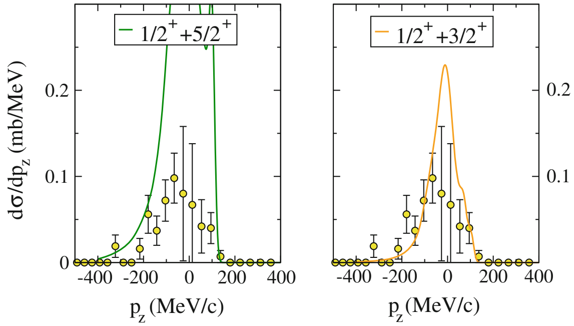


Fig. 1 Longitudinal momentum distribution for the reaction $^{20}C(p, pn)^{19}C$. The *left panel* includes an excited $5/2^+$ state of ^{19}C, while the *right panel* includes a $3/2^+$ state instead. The calculations consider the states of ^{19}C to be single-particle levels: $2s_{1/2}$, $1d_{5/2}$ and $1d_{3/2}$

on a basis of states of the $p - N$ subsystem with well-defined angular momentum, parity, and energy. Further details on the formalism are given in [1].

As an application of the formalism, we study the reaction $^{20}C(p, pn)^{19}C$ at 40 MeV/A. This reaction is of interest because it populates different states of ^{19}C, a nucleus whose structure is still unclear. Its ground state is known to have an angular momentum $1/2^+$ with neutron separation energy, S_n, of 0.58 MeV, but it has at least one excited state with yet undefined energy and angular momentum. Some structure models indicate it to be a $5/2^+$ state, while others favour a $3/2^+$ state, and some even predict two bound states with both angular momenta. In our contribution, we have performed two calculations, one with a $5/2^+$ bound state and the other with a $3/2^+$ bound state. The corresponding longitudinal momentum distributions, convoluted with the experimental resolution, are compared with the experimental data [2] on Fig. 1.

We find that the calculations agree better with the experimental data [2] when the $5/2^+$ state is unbound, so our calculation seems to favour structure models of ^{19}C with an unbound $5/2^+$ state. This result is consistent with previous studies of this nucleus [3]. Further details on the results and calculations are left for a future publication.

References

1. A.M. Moro, F. Nunes, Nucl. Phys. A **767**, 138 (2006); A.M. Moro, Phys. Rev. C. **92**, 044605 (2015)
2. A. Ozawa et al., Phys. Rev. C **84**, 064315 (2011)
3. N. Kobayashi et al., Phys. Rev. C **86**, 054604 (2012)

Sevilla, 23/01/2025
SERVICIO DE INVESTIGACIÓN

VICERRECTORADO DE INVESTIGACIÓN

ASUNTO
Proyectos participados

DESTINATARIO
D. Mario Gómez Ramos
Dpto. Física Atómica, Molecular y Nuclear
Facultad de Física

D. Julián Martínez Fernández, Vicerrector de Investigación de la Universidad de Sevilla

INFORMA

Que según los antecedentes que obran en este Servicio, D. Mario Gómez Ramos, con DNI 28839143H, ha participado en las siguientes actividades de Investigación:
Proyectos con participación:
- Proyectos de investigación:

- *Reacciones inducidas por interacciones Electrodébiles y Nucleares a energías bajas e intermedias*
  Plan Estatal 2021-2023 - Proyectos Investigación No Orientada, Duración: del 01/09/2024 al 31/08/2027, Referencia: PID2023-146401NB-I00, Importe: 144125.00 € . Participa como Equipo de Investigación.
- *EUROpean Laboratories for Accelerator Based Science - EURO-LABS*
  Horizon Europe, Duración: del 01/09/2022 al 31/08/2026, Referencia: 4598/1176, Importe: 155000.00 € . Participa como Contratado Postdoctoral.
- *Procesos de dispersión fuerte, electromagnética y débil con núcleos a energías bajas e intermedias*
  Plan Estatal 2017-2020 Generación Conocimiento - Proyectos I+D+i, Duración: del 01/09/2021 al 31/08/2025, Referencia: PID2020-114687GB-I00, Importe: 145200.00 € . Participa como Equipo de Trabajo.
- *Reacciones y Estructura nucleares: interacción eutrino-núcleo, Abundancias elementales del Cosmos, evolución Estelar y procesos Radiativos (RENACER)*
  PAIDI 2020: Proyectos I+D+i, Duración: del 05/10/2021 al 31/03/2023, Referencia: P20_01247, Importe: 76850.00 € . Participa como Equipo Colaborador.
- *Estudios de Procesos de Dispersión Fuerte y Electrodébil con Núcleos a Energías Bajas e Intermedias*
  Plan Estatal 2013-2016 Excelencia - Proyectos I+D, Duración: del 01/01/2018 al 30/09/2021, Referencia: FIS2017-88410-P, Importe: 90750.00 € . Participa como Equipo de Trabajo.
- *Estructura de Núcleos, Moléculas y Hadrones y su Dinámica en Procesos de Dispersión Fuerte y Electrodébil*
  Plan Estatal 2013-2016 Excelencia - Proyectos I+D, Duración: del 01/01/2015 al 30/06/2018, Referencia: FIS2014-53448-C2-1-P, Importe: 72600.00 € . Participa como Equipo de Trabajo.
- *Desarrollos en Teoría de Reacciones y Cálculos para la Interpretación de Experimentos con Núcleos Exóticos*
  Plan Estatal 2013-2016 Excelencia - Proyectos I+D, Duración: del 01/01/2014 al 30/06/2016, Referencia: FIS2013-41994-P, Importe: 18150.00 € . Participa como Equipo de Trabajo.
- *La Física Nuclear Fuera del Valle de Beta-Estabilidad: Sus Implicaciones en Astrofísica*
  Proyectos de Excelencia de la Junta de Andalucía, Duración: del 26/03/2013 al 31/03/2018, Referencia: P11-FQM-7632, Importe: 176918.30 € . Participa como Investigador.
- *European Nuclear Science and Application Research 2. (ENSAR2)*
  Horizonte 2020, Duración: del 01/03/2016 al 31/08/2021, Referencia: H2020-654002, Importe: 159343.53 € . Participa como Contratado Cap. 6 del 15/12/2018 al 04/03/2019.

Nota: La duración y el importe indicados anteriormente se corresponden con los datos obtenidos para el proyecto completo y no únicamente para el periodo en el que el investigador haya trabajado en él.

Fdo.: **Julián Martínez Fernández**
Vicerrector de Investigación

CERTIFICADO DE REALIZACIÓN DE COLABORACIÓN CIENTÍFICA

Apellidos, nombre/Surname, Name: Gómez Ramos, Mario	NIF/NIE: 28839143-H
Centro de origen/ Home Institution: UNIVERSIDAD DE SEVILLA	
ORGANISMO DE I+D RECEPTOR/ HOST INSTITUTION: University of Osaka	
CENTRO/ CENTER: Research Center for Nuclear Physics (RCNP)	
DEPARTAMENTO/DEPARTMENT: Theory Group	
PAÍS/COUNTRY: Japón	

El abajo firmante certifica que el/la investigador/a a quien se refiere el presente documento ha permanecido en el centro de trabajo desde el día 31 de enero de 2017 hasta el día 10 de marzo de 2017. Durante este periodo, el investigador y el grupo científico receptor han llevado a cabo una colaboración científica. **(*)**

Nombre y apellidos del firmante/ Name and surname of signatory: Kazuyuki Ogata

Cargo/Position: Associate Professor

Fecha/Date: 9th March, 2017

緒方一介

大阪大学核物理研究センター長

Firma y sello/ Signature and seal

(*) TO BE COMPLETED BY THE HOST RESEARCH DIRECTOR

The undersigned certifies that the scholar has remained in this centre from 31st January of 2017 until 10th March of 2017. During this period, a scientific collaboration project has been performed by the scholar and the host scientific group.

CERTIFICADO DE REALIZACIÓN DE COLABORACIÓN CIENTÍFICA

Apellidos, nombre/Surname, Name: Gómez Ramos, Mario	NIF/NIE: 28839143-H
Centro de origen/ Home Institution: UNIVERSIDAD DE SEVILLA	
ORGANISMO DE I+D RECEPTOR/ HOST INSTITUTION: University of Surrey	
CENTRO/ CENTER: Faculty of Engineering and Physical Sciences	
DEPARTAMENTO/DEPARTMENT: Department of Physics	
PAÍS/COUNTRY: Reino Unido	

El abajo firmante certifica que el/la investigador/a a quien se refiere el presente documento ha permanecido en el centro de trabajo desde el día 8 de octubre de 2017 hasta el día 3 de diciembre de 2017. Durante este periodo, el investigador y el grupo científico receptor han llevado a cabo una colaboración científica. **(*)**

Nombre y apellidos del firmante/ Name and surname of signatory: Dr N.K. Timofeyuk

Cargo/Position: Senior Research Fellow

Fecha/Date: 27/11/17

UNIVERSITY OF SURREY
Physics Department
University of Surrey
Guildford Surrey
GU2 7XH
Tel: 01483 686800
Fax: 01483 686781

Firma y sello/ Signature and seal

(*) TO BE COMPLETED BY THE HOST RESEARCH DIRECTOR

The undersigned certifies that the scholar has remained in this centre from 8th of Octoberof 2017 until 3rd of December of 2017. During this period, a scientific collaboration project has been performed by the scholar and the host scientific group.

EUROSCHOOL ON EXOTIC BEAMS

DIPARTIMENTO DI FISICA E ASTRONOMIA "G. GALILEI" – UNIVERSITÀ DEGLI STUDI DI PADOVA
ISTITUTO NAZIONALE DI FISICA NUCLEARE – Sezione di Padova and Laboratori Nazionali di Legnaro
http://www.euroschoolonexoticbeams.be/

Certificate
Poster presentation

This certificate confirms that

Mario GÓMEZ RAMOS

has presented a poster on

"Dynamical effects for transfer reactions in the DWBA approximation"

during the Euroschool on Exotic Beams, that was held in Padova, Italy, from September 7 - 13, 2014.

Director Euroschool 2014
Prof. Silvia M. Lenzi

Westfälische
Wilhelms-Universität
Münster

institut für
theoretische physik

Wilhelm-Klemm-Straße 9
48149 Münster

Bearbeiterin Katharina Krist
Tel. +49 251 83-34910
Fax +49 251 83-36328

katharina.krist@uni-muenster.de

Datum 12th February 2015

"Konferenz Complex Systems: Nano to Continuum"
10th - 12th February 2015, Universität Münster

CERTIFICATE OF PARTICIPATION AND ORAL CONTRIBUTION

Mr. Mario Gómez Ramos from the Physics Department of the University of Sevilla participated on the above-mentioned conference and gave an oral contribution with the title "Scattering and structure of quantum systems within few-body models".

February, 12th 2015

Linz
Prof. Dr. S. J. Linz

Westfälische Wilhelms - Universität
Institut für Theoretische Physik
Wilhelm-Klemm-Straße 9
48149 Münster

Wilhelms-Universität Münster

Rábida 15

International Scientific Meeting on Nuclear Physics

INTERNATIONAL SCIENTIFIC MEETING ON NUCLEAR PHYSICS

Basic concepts in Nuclear Physics: theory, experiments and applications

http://institucional.us.es/rabida

I hereby **CERTIFY** that

MARIO GÓMEZ RAMOS has actively participated in the INTERNATIONAL SCIENTIFIC MEETING ON NUCLEAR PHYSICS: "Basic concepts in Nuclear Physics: theory, experiments and applications", held at La Rábida (Huelva), Spain from June 1 to 5, 2015; and has presented a seminar at this meeting entitled

"TRANSFER TO THE CONTINUUM CALCULATIONS OF QUASIFREE (P, PN) AND (P, 2P) REACTIONS AT INTERMEDIATE AND HIGH ENERGIES"

On behalf of the local organizing committee

La Rábida (Huelva), June 5, 2015

Signature

Nucleus Nucleus 2015

Contribution ID : 130

Transfer to the continuum calculations of quasifree (p,pn) and (p,2p) reactions

Primary authors : Mr. GOMEZ RAMOS, Mario (University of Seville) ; Mr. ANTONIO, Moro (Universidad de Sevilla, Spain)

Co-authors :

Presenter : Mr. GOMEZ RAMOS, Mario (University of Seville)

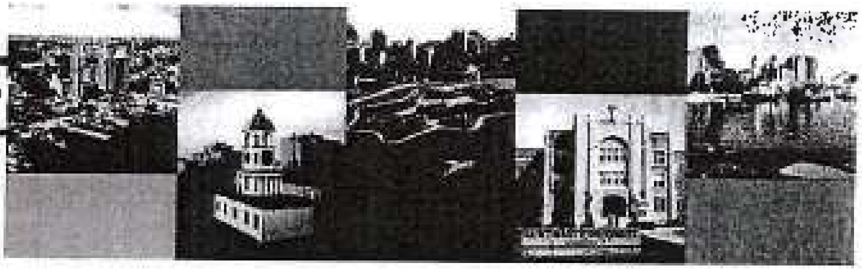
Session classification : Reactions and Structure - Unstable Nuclei

Track classification : Reactions and Structure - Unstable Nuclei

Type : Poster

DREB2016
Direct Reactions with Exotic Beams

Halifax, Canada



TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

July 13, 2016

Mr. Mario Gomez-Ramos
Universidad de Sevilla
Facultad de FÍsica, 6ª planta
C/ Reina Mercedes s/n
Sevilla, Spain
41012
email: mgomez40@us.es

To Whom It May Concern,

LETTER OF ATTENDANCE

Please accept this letter as confirmation that Mr. Mario Gomez-Ramos attended the 9th International conference on Direct Reactions with Exotic Beams (DREB 2016), in Halifax, Nova Scotia, Canada. July 11-15, 2016. He presented a talk on Friday, July 15, and presented poster #76.

The talk given was: Abstract #75: ***Transfer to the continuum calculations of quasifree (p,pn) nd (p,2p) reactions.***

Regards,

Ms. Jana Thomson,
Conference Coordinator
DREB2016

DREB 2016 - POSTER PRESENTATIONS

Abstract ID	Title of Poster	Presenter
19	Radioactive ion beam reactions studied using the VANDLE scintillator array	Cory Thornsberry
21	Investigation of Hg isotopes via reactions	Alejandra Diaz Varela
22	Hybrid array of gamma ray detectors (HAGRiD)	Karl Smith
26	Development of a novel hybrid ionization chamber / double-sided-silicon-strip detector to be installed at the DRAGON laboratory at TRIUMF	Devin Burke
36	Constraining reaction theory uncertainties in elastic, inelastic, and transfer cross sections	Amy Lovell
42	Experimental study of the structure of the ^{19}F nuclei at low energies for nuclear physics and astrophysics	Nunzia Simona Martorona
45	Studying the structure of ^{8}B through direct reactions	Jiansong Wang
53	Reducing ambiguities in spectroscopic factors with combined measurements and the ^{86}Kr(d,p) reaction at 35 MeV/u	David Walter
56	Influence of the ^{14}C-n continuum on the extraction of ^{14}C(n,γ^{15}C cross section from the measurement of ^{15}C Coulomb breakup	Pierre Capel
59	IRIS : A reaction spectroscopy facility with solid H2/D2 target	Matthias Holl
67	Investigating the single-particle and the alpha-cluster state via knockout reaction	Kazuki Yoshida
76	Interplay between breakup of weakly bound nuclei and collective excitation	Maria Gomez-Ramos
79	EMMA status and commissioning	Matthew Williams
82	Effect of three nucleon force from chiral effective field theory on nucleon-nucleus and nucleus-nucleus elastic scattering	Masakazu Toyokawa
85	One-proton breakup reactions of proton-rich p(sd)- shell nuclei for relevant reaction rates in explosive hydrogen burning	Andriana Banu
89	Direct measurements of key α-capture reaction rates using the MUSIC detector	Melina Avila
95	Remeasurement of the proton resonance elastic scattering of ^{34}Si	Noritaka Kitamura
105	Continuum spectrum and Feshbach's doorway-state resonance	Takaharu Otsuka
113	Investigating the nature of excited 0^+ states populated via the ^{162}Er(p,t) reaction	Christina Burbadge
115	Direct and resonant reactions with the Active Target Time Projection Chamber (AT-TPC) and MAIKo active targets	Yassid Ayyad

CPAN
ingenio 2010

CENTRO NACIONAL DE FÍSICA DE
PARTÍCULAS ASTROPARTÍCULAS Y NUCLEAR
Red Consolider CPAN

ANTONIO PICH ZARDOYA, organizador de las VIII Jornadas CPAN

C E R T I F I C A:

1.- Que Mario GÓMEZ ha participado en los VIII CPAN DAYS, que han tenido lugar en Zaragoza durante los días 28 - 30 de noviembre de 2016.

2.- Que intervino con una conferencia invitada titulada: "Transfer to the continuum calculations for (p,pN) and transfer reactions on Borromean nuclei".

Y para que conste, a los efectos oportunos, lo firmo en Paterna, a dos de diciembre de 2016.

Fdo.: Antonio Pich Zardoya

Real Sociedad Española de Física

R.S.E.F.

XXXVI Reunión Bienal de la Real Sociedad Española de Física

27 Encuentro Ibérico de Enseñanza de la Física

Certificado otorgado a **Mario Gómez Ramos** por haber presentado la siguente comunicación oral: **Transfer to the continuum calculations of (p, pn) and (p, 2p) reactions at intermediate and high energies. Application to Borromean nuclei** en el Simposio **Física Nuclear** de la XXXVI Reunión Bienal de la Real Sociedad Española de Física (17-21 de julio de 2017) organizado por la Real Sociedad Española de Física.

Santiago de Compostela 21 de julio de 2017

Dolores Cortina Gil
Presidenta del Comite Organizador de la XXXVI Bienal de la RSEF

Elena López-Lago
Vice Presidenta del Comite Organizador de la XXXVI Bienal de la RSEF

SC Universidade de Santiago de Compostela · Deputación da Coruña · Concello de Santiago · Santiago de Compostela · Santiago de Compostela Convention Bureau · Hamamatsu · Ibiaciencia · ATI Sistemas · Sidilab

UNIVERSITY of York

Department of Physics

This is to certify that

Mario Gómez

attended the

The 3rd International Workshop on Quasi-Free Scattering with Radioactive-Ion Beams (QFS-RB 17) at York, UK

24th to 27th July, 2017

and gave a presentation with title:

"Transfer to the continuum calculations of (p, pn) and (p, 2p) reactions at intermediate and high energies

STEFANOS PASCHALIS
ON BEHALF OF THE ORGANISING COMMITTEE
27//07/2017, YORK, UK

YORK

HIC for FAIR Helmholtz International Center

UNIVERSITY of York

IOP Institute of Physics

Atomic, Molecular, and Nuclear Physics Department
University of Seville

José Antonio Lay Valera
Facultad de Física
Apartado 1065
E 41080 SEVILLA
SPAIN

UNIVERSIDAD DE SEVILLA
FACULTY OF PHYSICS

Tel.:+34954559993
Fax:+34954554445
E Mail: lay@us.es

February 14, 2019

To whom it may concern,

This is to certify that Dr. Mario Gómez Ramos gave a talk entitled **Study of "quenching factors" for (p,pn) and (p,2p) reactions through the Transfér to the Continuum formalism** on the 5^{th} of March, 2018, as an oral contribution to the workshop **Recent advances and challenges in the description of nuclear reactions at the limit of stability** held at the ECT* at Trento, Italy, from the 5^{th} to the 9^{th} of March, 2018.

Yours sincerely,

José Antonio Lay Valera
Member of the Organizing Committee

DREB 2018 DIRECT REACTIONS with EXOTIC BEAMS

Matsue, Japan, June 4-8, 2018

Date: June 6, 2018

Certificate

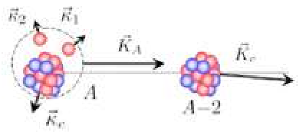
This is to certify that

Mario Gomez Ramos

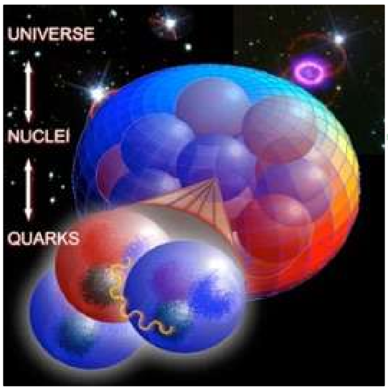
has participated in the Conference on Direct reactions with EXOTIC BEAMS 2018 (DREB2018) held in Matsue in Japan on June 4-8, 2018 and presenting "Analysis of isospin dependence of "quenching factors" for (p,pn) and (p,2p) reactions via the Transfer to the Continuum formalism" .

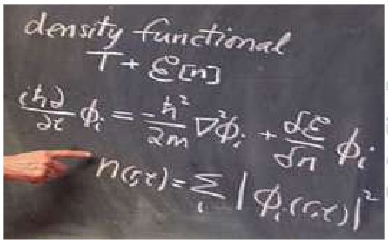
Kazuyuki OGATA
Co-Chair, DREB2018 緒方一介

Contact: ml-dreb2018-contact@rcnp.osaka-u.ac.jp



Main page **Travel & Accommodation**





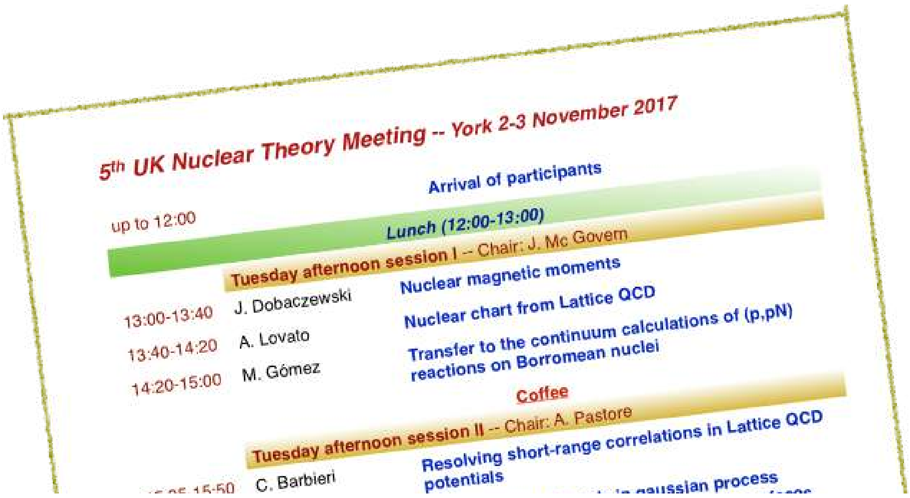
Time schedule (see full program below):

2 November:
12-13 Lunch
13-15 Talks
15-15:30 Coffee break
15:30-17:30 Talks
18-20 Dinner in town

3 November:
9-11 Talks
11-11:30 Coffee break
11:30-12:30 Discussions
12:30-13:30 Lunch

List of talks - *to be updated in the coming days...*:

A. Lovato - "Nuclear chart from Lattice QCD."
C. Barbieri - "Resolving short-range correlations in Lattice QCD potentials."
J. Dobaczewski - "Nuclear magnetic moments"
R. Smith - "Direct 3-α Decay from the Hoyle State."
A. Pastore - "Can we build an effective 2-body interaction with a reasonable effective mass?"
N. Rocco - "Inclusive electron-nucleus cross sections within the SCGF and GFMC approaches."
M. Shelley - "Non-stationary kernels in gaussian process regression for fission potential energy surfaces."
M. Dinmore - "D-state & energy dependence in transfer reactions."
C. McIlroy - "Calculations of Infinite Matter in a Periodic Box."
M. Gómez - "Transfer to the continuum calculations of (p,pN) reactions on Borromean nuclei."
A. Mantziris - "Density Functional Theory applied for the description of Neutron Stars: the dibaryon as a new degree of freedom."
A. Romero - "Neutron-proton correlations in atomic nuclei."
M. Barton - "Symmetry Unrestricted Self Consistent Time Dependent Density Matrix Theory with a Skyrme force."
N. Timofeyuk - "Three-nucleon force effects in (d,p) reactions."


5th UK Nuclear Theory Meeting -- York 2-3 November 2017

up to 12:00		Arrival of participants
		Lunch (12:00-13:00)
		Tuesday afternoon session I -- Chair: J. Mc Govern
13:00-13:40	J. Dobaczewski	Nuclear magnetic moments
13:40-14:20	A. Lovato	Nuclear chart from Lattice QCD
14:20-15:00	M. Gómez	Transfer to the continuum calculations of (p,pN) reactions on Borromean nuclei
		Coffee
		Tuesday afternoon session II -- Chair: A. Pastore
	C. Barbieri	Resolving short-range correlations in Lattice QCD potentials

15:35-1…		
15:50-16:10	M. Shelley	Non-stationary kernels in gaus… regression for fission potential energy surfaces
16:10-16:30	A. Romero	Neutron-proton correlations in atomic nuclei
16:30-16:50	C. McIlroy	Calculations of Infinite Matter in a Periodic Box
16:50-17:10	M. Dinmore	D-state & energy dependence in transfer reactions
17:10-17:30	N. Timofeyuk	Three-nucleon force effects in (d,p) reactions.
		Dinner at Barbakan — 18:30
		Wednesday morning session -- Chair: F. Raimondi
9:00-9:40	A. Pastore	Can we build an effective 2-body interaction with a reasonable effective mass?
9:40-10:20	N. Rocco	Inclusive electron-nucleus cross sections within the SCGF and GFMC approaches
10:20-10:40	M. Barton	Symmetry Unrestricted Self Consistent Time Dependent Density Matrix Theory with a Skyrme force
10:40-11:00	A. Mantziris	Density Functional Theory applied for the description of Neutron Stars: the dibaryon as a new degree of freedom
		Coffee
		Open discussions
11:30-12:30		***Lunch and farewell (12:30-13:30)***
		Departure

Last updated: Tuesday 31st of October, 2017

00:00:00:00
Days Hours Mins Secs

IGFAE Instituto Galego de Física de Altas Enerxías · USC · XUNTA DE GALICIA

DREB 2022

CERTIFICATE OF PARTICIPATION

This is to certify that **Mario Gomez Ramos** participated in the **11th international conference on Direct Reactions with Exotic Beams (DREB2022),** held in Santiago de Compostela, Spain, from June 26th to July 1st, 2022, and gave the talk **Core-valence absorption in breakup reactions: a source of binding-energy asymmetry in nucleon removal observables?** on June 29th.

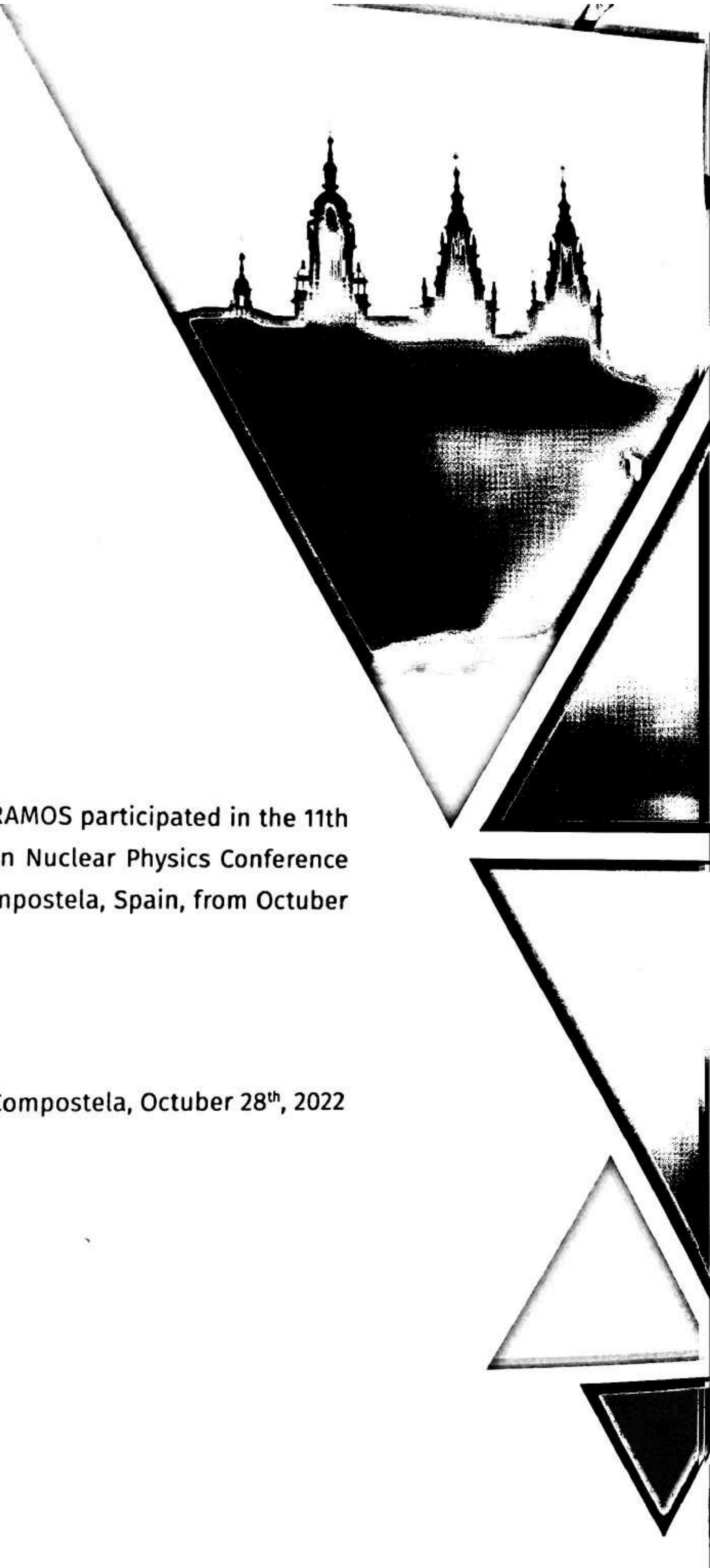
Santiago de Compostela, July 1st, 2022

Signed,

D. Cortina

Dolores Cortina
Chair of the Local Committee

IGFAE USC XUNTA DE GALICIA



EUROPEAN NUCLEAR PHYSICS CONFERENCE

SANTIAGO DE COMPOSTELA, SPAIN

October 24th - 28th 2022

This is to certify that MARIO GOMEZ RAMOS participated in the 11th international conference on European Nuclear Physics Conference (EuNPC2022), held in Santiago de Compostela, Spain, from Octuber 24th to 28th, 2022.

Santiago de Compostela, Octuber 28th, 2022

Signed,

D. Cortina

Dolores Cortina
Chair of the Local Committee

Xacobeo 21·22 UNIÓN EUROPEA XUNTA DE GALICIA

2022 EUROPEAN NUCLEAR PHYSICS CONFERENCE

Santiago de Compostela, Spain,

October 24th - 28th 2022

https://indico.cern.ch/e/EUNPC2022

Monday, 1 August 2022
Mario Gómez Ramos
Universidad de Sevilla
Sevilla (Spain)

Dear Mario Gómez Ramos,

I am writing on behalf of the organising committee to extend you a formal invitation to give a **invited parallel session talk** at the European Nuclear Physics Conference (EuNPC). The conference will be held on 24 -28 October 2022 at the University of Santiago de Compostela North Campus, in Santiago de Compostela, Spain.

Further information regarding the precise timing of your talk will be sent to you once the programme has been confirmed. In the meantime, please refer to the website at https://indico.cern.ch/event/1104299/ for further information.

Invited talks will be approximately 20 minutes in duration (including discussion). The organising committee encourages speakers to leave some time at the end of their presentation for questions from the audience so please save the last 5.

The organising committee has indicated the subject of your talk would be **Core-valence absorption in breakup and stripping reactions and its isospin dependence**. In order to update the website, could you please either send me or uploading in the indico webpage https://indico.cern.ch/event/1104299/abstracts/ at your earlier convenience.

Please note as an invited speaker at EuNPC 2022, you will be responsible to cover your registration fee and travel expenses. This enables the student registration fee to be kept low, increasing the numbers that can attend the conference. In case you might need ecconomical support please, do not doubt to contact us.

If you need any assistance please contact us eunpc2022@igfae.usc.es

Lola Cortina and Elena González

Chair of the EuNPC 2022

DREB 2024

12th international conference on
Direct Reactions with Exotic Beams

Certificate of contribution in DREB 2024 Conference

To Whom It May Concern,

I am writing to confirm that Mario Gomez-Ramos presented the talk “Effect of valence-core destruction in the dependence on isospin asymmetry for single-nucleon knockout ‘quenching’ factors” in the Direct Reactions with Exotic Beams (DREB) 2024 conference on June 24, 2024 in Wiesbaden, Germany.

Sincerely,

Kathrin Wimmer

Dr. Kathrin Wimmer,
on behalf of the organisation of DREB 2024 (Aumann, Duer, Obertelli, Simon, Wimmer)

BF 20 24

Musikene · Escuela de Ingenieros de Gipuzkoa

15-19 JULIO 2024

CERTIFICADO

XXXIX Reunión Bienal de la Real Sociedad Española de Física

Por la presente confirmamos que,

Mario GOMEZ RAMOS

ha presentado una comunicación Oral en la XXXIX Reunión Bienal de la Real Sociedad Española de Física celebrada del 15 al 19 de julio de 2024 en Donostia-San Sebastián.

Para que así conste, a los efectos que fuera oportuno, firma el presente certificado.

Jenaro Guisasola

Presidente del Comité Organizador

DR. Jenaro Guisasola

DEPARTAMENTO DE FÍSICA ATÓMICA, MOLECULAR Y NUCLEAR

Universidad de Sevilla

Facultad de Física
Apdo 1065
41080 Sevilla, SPAIN

Tel.: (+34) 954 55 99 93
Fax: (+34) 954 55 44 45
e-mail: miancortes@us.es

Seville, October 1st, 2015

TO WHOM IT MAY CONCERN:

I declare by this document that **Mr. Mario Gómez-Ramos**, Ph.D. Student at Universidad de Sevilla, presented a talk entitled "*Transfer to the continuum calculations of (p, pN) reactions at intermediate and high energies*" on June 12th, 2015, as part of the Seminar Series held at the Department of Atomic, Molecular and Nuclear Physics.

If any further information is needed, please do not hesitate to contact me.

Sincerely,

Miguel Antonio Cortés-Giraldo, Ph.D.
Assistant Professor
Dep. Atomic, Molecular and Nuclear Physics
Universidad de Sevilla

FACULTAD DE FÍSICA

Dª GLORIA HUERTAS SÁNCHEZ, PROFESORA TITULAR Y VICEDECANA DE INNOVACIÓN DOCENTE DE LA FACULTAD DE FÍSICA DE LA UNIVERSIDAD DE SEVILLA,

HACE CONSTAR:

Que según los antecedentes que obran en esta Secretaría **D. MARIO GÓMEZ RAMOS** ha participado en las actividades de divulgación **QUIFIBIOMAT 2016** y en la **Feria de la Ciencia 2017** organizadas por la Facultad de Física

Y para que conste a los efectos oportunos firmo el presente en Sevilla, a cuatro de febrero de dos mil diecinueve.

UNIVERSIDAD DE SEVILLA
FACULTAD DE FÍSICA

Fdo.: Gloria Huertas Sánchez

MARÍA DEL CARMEN GALLARDO CRUZ, VICERRECTORA DE ESTUDIANTES DE LA UNIVERSIDAD DE SEVILLA

HACE CONSTAR:

Que, a la vista de los informes de los responsables del Centro/Servicio, Facultad de Física, D/D.ª **MARIO GOMEZ RAMOS** con DNI **28839143H** ha participado en calidad de colaborador/a en el ***XXIX SALÓN DE ESTUDIANTES DE GRADO Y POSGRADO, Y FERISPORT 2025,*** organizado por el Vicerrectorado de Estudiantes de la Universidad de Sevilla y realizado en el Complejo deportivo universitario Los Bermejales, durante los días 24 al 29 de marzo de 2025.

De todo ello se informa a los efectos oportunos.

LA VICERRECTORA,

Fdo.: María del Carmen Gallardo Cruz

DEPARTAMENTO DE FÍSICA ATÓMICA, MOLECULAR Y NUCLEAR

Facultad de Física. Universidad de Sevilla

D. ANTONIO MORO MUÑOZ, PROFESOR TITULAR DE LA UNIVERSIDAD DE SEVILLA Y SECRETARIO DEL DEPARTAMENTO DE FÍSICA ATÓMICA, MOLECULAR Y NUCLEAR,

CERTIFICA QUE

Según la documentación que obra en la Secretaría de este departamento, **D. Mario Gómez Ramos**, ha sido miembro de las siguientes comisiones del departamento de FAMN:

- Comisión de Investigación (miembro titular): desde 22 de marzo de 2018 hasta 21 de octubre de 2018.
- Comisión Electoral (miembro suplente); desde 22 de marzo de 2018 hasta 21 de octubre de 2018.

La composición y competencias de dichas comisiones están recogidas en los Estatutos de la Universidad de Sevilla y el Reglamento de Funcionamiento del Consejo de Departamento.

Y, parte que así conste, firmo la presente en Sevilla a 6 de febrero de 2019.

EL SECRETARIO

DocuSigned by:

068B1DFC083F417...

Fdo: Antonio M. Moro Muñoz

Secretariado de Innovación Educativa
Dirección General de Formación Continua y Complementaria

JULIO CABERO ALMENARA, DIRECTOR DEL SECRETARIADO DE INNOVACIÓN EDUCATIVA DE LA UNIVERSIDAD DE SEVILLA

HACE CONSTAR:

Que D/Dª. MARIO GOMEZ RAMOS, con documento identificativo 28839143H, ha participado en la acción formativa COMPETENCIAS NIVEL I: INTEGRACIÓN DE LA PREVENCIÓN DE RIESGOS LABORALES Y COMPETENCIAS ESPECÍFICAS DEL PERSONAL INVESTIGADOR DE LA UNIVERSIDAD DE SEVILLA (modalidad on line), finalizada el 12 de Noviembre de 2023, con un total de 15 HORAS ON-LINE.

Y para que conste y surta los efectos oportunos, firmo el presente en Sevilla a la fecha de la firma.

Fdo.: Julio Cabero Almenara

Certificado nº 165198

TEMARIO DE LA ACCIÓN FORMATIVA

OBJETIVO

Conocer los aspectos básicos de la prevención de riesgos laborales en la Universidad y aplicar e impulsar el establecimiento de medidas preventivas en su actividad docente tanto en aulas y despachos, como en laboratorios y/o talleres donde se imparta docencia, colaborando en el ámbito de sus competencias en la mejora de sus condiciones de trabajo.

CONTENIDO

COMÚN:

MÓDULO 1:

Introducción a la prevención de riesgos laborales.
Conceptos básicos de seguridad y salud en el trabajo.
Marco normativo básico en prevención de riesgos laborales.
Derechos y obligaciones.
Gestión de la prevención en la empresa-Universidad de Sevilla.

MÓDULO 2:

Riesgos del puesto de trabajo: Tareas docentes en aulas/seminarios y tutorías en despachos.

MÓDULO 3:

Medidas de Emergencia y Evacuación.
Medicina del Trabajo.

ESPECÍFICO:

MÓDULO 4:

Riesgos específicos en laboratorios: Químico-Biológico.
Riesgos específicos en laboratorios: Físico-Mecánico.

JULIO CABERO ALMENARA, DIRECTOR DEL SECRETARIADO DE INNOVACIÓN EDUCATIVA DE LA UNIVERSIDAD DE SEVILLA

HACE CONSTAR:

Que D/Dª. MARIO GOMEZ RAMOS, con documento identificativo 28839143H, ha participado en la acción formativa ALTERACIONES Y EDUCACIÓN DE LA VOZ I, finalizada el 9 de Mayo de 2024, con un total de 7 HORAS.

Y para que conste y surta los efectos oportunos, firmo el presente en Sevilla a la fecha de la firma.

Fdo.: Julio Cabero Almenara

Certificado nº 167219

TEMARIO DE LA ACCIÓN FORMATIVA

OBJETIVOS:

* Abordar la patología de la fonación como enfermedad relacionada con el trabajo y tratar las patologías más frecuentes que inciden en el aparato fonador.
* Conocer las características y mecanismos de la voz, así como la necesidad de hablar correctamente.
* Detectar los factores de riesgo de la voz incidiendo en los producidos por la docencia.
* Asumir que la utilización correcta de la voz y el habla son factores decisivos que inciden en la salud personal y laboral.

CONTENIDOS:

0.- Protocolo de Acoso de la Universidad de Sevilla: Los códigos éticos de conducta e información general.
1. Prevención de Riesgos Laborales: Prevención de Riesgos Laborales: Guía Preventiva para los trabajadores de la Universidad. La patología de la fonación como enfermedad relacionada con el trabajo.
2. Otorrinolaringología: Conceptos básicos sobre anatomía y fisiología del aparato buco-fonatorio. Patologías más frecuentes que inciden el aparato fonador del docente y medidas de prevención. Conceptos básicos sobre fonación.
3. Logopedia: Los procesos de la fonación. Características de la voz profesional: Condiciones indispensables. Hábitos saludables en torno a la voz. Características de la respiración y ejercicios. Relajación muscular y mental. Recomendaciones para mejorar las condiciones de la voz.

JULIO CABERO ALMENARA, DIRECTOR DEL SECRETARIADO DE INNOVACIÓN EDUCATIVA DE LA UNIVERSIDAD DE SEVILLA

HACE CONSTAR:

Que D/Dª. MARIO GOMEZ RAMOS, con documento identificativo 28839143H, ha participado en la acción formativa COMPETENCIAS NIVEL I: INTEGRACIÓN DE LA PREVENCIÓN DE RIESGOS LABORALES Y COMPETENCIAS ESPECÍFICAS DEL PERSONAL INVESTIGADOR DE LA UNIVERSIDAD DE SEVILLA (modalidad on line), finalizada el 22 de Septiembre de 2024, con un total de 15 HORAS ON-LINE.

Y para que conste y surta los efectos oportunos, firmo el presente en Sevilla a la fecha de la firma.

Fdo.: Julio Cabero Almenara

Certificado nº 174383

TEMARIO DE LA ACCIÓN FORMATIVA

OBJETIVO

Conocer los aspectos básicos de la prevención de riesgos laborales en la Universidad y aplicar e impulsar el establecimiento de medidas preventivas en su actividad docente tanto en aulas y despachos, como en laboratorios y/o talleres donde se imparta docencia, colaborando en el ámbito de sus competencias en la mejora de sus condiciones de trabajo.

CONTENIDO

COMÚN:

MÓDULO 1:

Introducción a la prevención de riesgos laborales.
Conceptos básicos de seguridad y salud en el trabajo.
Marco normativo básico en prevención de riesgos laborales.
Derechos y obligaciones.
Gestión de la prevención en la empresa-Universidad de Sevilla.

MÓDULO 2:

Riesgos del puesto de trabajo: Tareas docentes en aulas/seminarios y tutorías en despachos.

MÓDULO 3:

Medidas de Emergencia y Evacuación.
Medicina del Trabajo.

ESPECÍFICO:

MÓDULO 4:

Riesgos específicos en laboratorios: Químico-Biológico.
Riesgos específicos en laboratorios: Físico-Mecánico.

FONDAZIONE BRUNO KESSLER

ECT*
EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS

CERTIFICATE OF ATTENDANCE

To whom it may concern,

Trento, 07/07/2025

this is to certify that **Mario Gomez Ramos** has participated in the workshop "**Theory Service for the Low Energy Nuclear Physics Community: a Hands-on Workshop**", held in the period **07/07/2025 - 09/07/2025** at the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), in Trento, Strada delle Tabarelle n. 286.

Yours sincerely,

Ubirajara van Kolck
Director of ECT*